A ROCK CLASSIFICATION SYSTEM FOR APPLICATION IN UNDERGROUND COAL MINING

PREPARED FOR THE

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Attention: Dr. B. Das, P. Eng.
Scientific Authority

Our Ref : 6700

Subject : A Rock Classification System for Application in Underground Coal Mining. DSS Contract 0SQ82-00113

Dear Dr. Das:

We are pleased to submit to you our report on the classification system we propose for roof and floor rocks in Canadian coal mines.

It has been a pleasure to work on this important assignment, the first step in providing Canadian coal mine planners with a tool that is being increasingly used in the major coal-producing countries of the world.

We look forward to a continuing association with CANMET on this and other projects.

Yours very truly,

R. Minto, Ph.D. P.Eng.
Vice-President
Mining and Metallurgy Division

A ROCK CLASSIFICATION SYSTEM

FOR APPLICATION IN UNDERGROUND COAL MINING

BY

SNC INC.

Work on this project was conducted under the auspices
of the Canada Centre for Mineral and Energy Technology
Energy, Mines and Resources Canada.

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SUMMARY

Under a contract awarded by Supply and Services Canada, SNC has carried out a study to develop a rock classification system for application in Canadian underground coal mines.

The scope of work included a literature review, an appraisal of the geological and geotechnical characteristics of the major Canadian coalfields, the collection of data and, based on these, the development of a classification system for roof and floor rocks.

Existing rock classification systems range from the earliest ones for civil engineering and tunnelling work through to the latest for roof and floor strata of coal mines. Most of the latter systems were developed for local mining areas or conditions in coalfields outside Canada. Due to the limited number and specific use of the parameters taken into account, none of these systems is suitable for general application in Canadian coalfields.

Canada's major coalfields are found in the Maritimes, Plains, Foothills and Mountain regions. They exhibit a wide range of geological conditions from gently-dipping seams up to 2 metres in thickness in the Sydney Coalfield to highly deformed, faulted coal measures in the Rocky Mountains, where seams can reach a thickness of 15 metres.

Visits were made to the Prince Mine in Nova Scotia, the Cardinal River, Coal Valley and Smoky River mines in Alberta and the Balmer Mine in British Columbia. Preliminary tests of rock strengths were made and the results analysed and plotted graphically to illustrate two of the most important properties of roof and floor rocks respectively: bed separation resistance and load bearing capacity.

In view of the wide variations in geological and geotechnical conditions in Canadian coalfields, the classification system proposed is based on the stability of roof and floor rocks as measured by two key parameters:

- Critical roof span; defined as the maximum diameter of a circular or semi-circular opening in which roof strata will remain in a self-supporting, stable condition over the period of time required for mining operations.

- Load bearing capacity; the ability of floor rocks to support equipment such as roof supports or rubber-tired vehicles.

Other important features such as rock slakeability (the effect on rock strength of exposure to water) and natural fractures (e.g. jointing) are taken into consideration in quantifying these parameters. Simple,

SUMMARY (Cont'd)

portable equipment is used to make underground measurements of the various parameters; alternatively, determinations can be made on the basis of tests carried out on drill core samples.

The respective classifications, with rock quality ranging from the poorest (Class 1) upwards, are illustrated below.

Roof strata have been divided into six classes. For non-homogeneous rocks, the classification is based on the critical roof span (CRS) as determined from field tests. For homogeneous rocks, classification is based on measurements of bed separation resistance (BSR).

Roof Class	Non-homogeneous Rock CRS (m)	Homogeneous Rock BSR (MPa)
1	0 - 2	0 - 0.5
2	2 - 4	0.5 - 1.5
3	4 - 6	1.5 - 3.0
4	6 - 8	3.0 - 4.5
5	8 - 10	4.5 - 6.0
6	10	6.0

Load bearing capacity (LBC) has been used as the main parameter in classifying floor rocks into four groups:

Floor Class	LBC (MPa)
1	0 - 3
2	3 - 10
3	10 - 25
4	25

SUMMARY (Cont'd)

These roof and floor rock classifications have been used in conjunction with a classification of coal seam parameters to propose a system which can be used to classify seam mineability. Classification is based on a weighted point rating assigned to each parameter and divides coal seams into five degrees of mineability ranging from "very good" to "not mineable at present stage of technology".

The rock classification system is an important tool in mine design with application in areas such as the prediction of caveability of roof strata, the selection of roadway and face supports and the determination of the length and spacing of roof bolts.

The classification of roof and floor rocks is the first step in evaluating the mineability of a coal seam and it is recommended that further work be carried out in the following areas:

- Classification of properties of the coal seam itself (cutting resistance, bursting potential, pillar stability, etc.) in addition to the properties of the roof and floor strata.

- Regional maps of roof conditions, based on bed separation resistance logs of all principal seams, to assist in selection of mining methods.

- Regional maps of floor conditions, based on measurements of properties such as load bearing capacity, to help in mine planning.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Meaning	Unit
BSR	Bed Separation Resistance	MPa
CFR	Core Fragmentation Ratio	-
CI	Core Index	-
CRR	Core Recovery Ratio	-
CRS	Critical Roof Span	m
CSR	Core Splitting Resistance	kN
FL	Load at Rock Failure	kN
HBP	Hydraulic Borehole Penetrometer	-
IIR	Impact Indentation Rate	mm
LBC	Load Bearing Capacity	MPa
PLSI	Point Load Strength Index	MPa
RMF	Rock Mass Factor	-
RQD	Rock Quality Designation	-
SF	Slakeability Factor	-
TS	Tensile Strength	MPa

Symbol	Meaning	Unit
d	Diameter of drill core specimen	cm
F	Rock sensitivity to fall	%
h	Thickness of immediate roof	m
l	Length of drill core specimen	cm
M	Extracted thickness of seam	m
P_k	Bearing capacity of floor rocks	MPa
P_m	Maximum oil pressure (in HBP)	MPa
t	Thickness of roof band to first separation plane	m

1.0 INTRODUCTION

1.0 INTRODUCTION

Ground control problems are among the major factors influencing the choice of methods of mining coal and affecting the techno-economic performance of the operation. It is therefore important that a suitable rock classification system be developed using the geotechnical characteristics of the roof and floor of the coal seam as a practical basis for geotechnical evaluation. Some work in this respect has been done for civil engineering tunnels but much less for underground coal mining purposes and almost none in Canada for its coal mining conditions. The problem is much more complex for mining than for civil engineering tunnels because of depth, geological conditions, complex networks of roadways, large spans of mined-out areas and the low cost and short term support systems that are used in mining.

The following report contains the results of a study whose objective was the development of a rock classification system for application in Canadian coal mines. The system is designed to be used in the prediction of strata behaviour and the selection of mining methods and support systems.

The work was carried out by SNC under a contract from Supply and Services Canada (DSS) on behalf of the Coal Research Laboratories of the Canada Centre for Mineral and Energy Technology (CANMET) in Calgary, Alberta. The contract was awarded on September 20 and work began on November 18, 1982.

In fulfilling the requirements of the contract, SNC, through its association with KOPEX, of Katowice, Poland, provided the services of Dr. Antoni Kidybinski, Deputy Director (Science) of the Central Mining Institute, Katowice, and Professor of Strata Control Engineering at the University of Krakow.

2.0 SCOPE OF STUDY

2.0 SCOPE OF STUDY

Under the title "To develop a rock classification system for application in underground coal mining"*, the scope of work was defined as follows:

- Conduct a literature review on rock classification in general and for underground coal mining purposes in particular.

- Identify the different geological areas of the Canadian coalfields that may have distinct characteristics for this classification e.g. Plains, Foothills, Mountain, Maritime, etc. The conditions of these fields should be taken into account in developing the classification system.

- Identify and describe geological and geotechnical parameters that influence the behaviour of the roof and floor rocks in coal measures, with special reference to Canadian coalfields.

- Collect and review data from the possible representative sites in Canada, including old mines (dormant), operating mines and new projects.

- Assess these areas as to mining methods in practice or any new methods which may appear to be suitable, e.g. room and pillar, longwall, shortwall, hydraulic, horizon or any others. This may be accomplished through literature surveys, discussion with operators and other organizations, as well as site visits.**

- Develop an empirical classification system for the various geotechnical conditions which may exist in the roof and floor of a coal seam.

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* Appendix "A", Contract OSQ82-00113, Supply and Services Canada

** It was agreed at the start of the study that the assessment would involve observation of current practices but not the consideration of new or different methods.

2.0 SCOPE OF STUDY (Cont'd)

- Analyze the data assembled for the purpose of fitting it to the classification system and relating this system to the various mining methods.

- Compile conclusions derived from this study, stressing as feasible the usefulness of the results.

3.0 MEETINGS AND FIELD TRIPS

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3.1 Meetings

At the outset of the study a meeting was held in the CANMET Office in Calgary on November 22, 1982, between members of SNC's study team and CANMET staff (Mr. G. Zahary, Manager Western Office and Dr. B. Das, Research Scientist and the Scientific Authority for this project). The scope of work was reviewed in detail and preparations were made for the field trip to various mines in Western Canada.

Following the trip, a further meeting was held with Dr. Das on December 3 to review results and discuss the proposed classification system.

3.2 Field Trips

Information on geotechnical conditions in the Sydney coalfield was gathered by Dr. Kidybinski in 1980 during a six-week study at the Prince Mine on behalf of the Cape Breton Development Corporation (CBDC). Further information on the Sydney coalfield was obtained by SNC in the course of a feasibility study, commissioned by CBDC, of a new mine to replace the present No. 26 Colliery. This work was performed in 1981.

To obtain geotechnical information on coalfields in Western Canada, a field trip was arranged from Calgary in the course of which the following mines were visited:

- November 26, 1982: Balmer North and Balmer South mines, B.C. Coal Ltd., Balmer, B.C.
- November 27, 1982: Greenhills mine, B.C. Coal Ltd., Harmer, B.C.
- November 29, 1982: Cardinal River mine, Cardinal River Coals Ltd., Cardinal River, Alberta.

  Coal Valley mine, Luscar Sterco, Coal Valley, Alberta.

3.0 MEETINGS AND FIELD TRIPS (Cont'd)

3.2 Field Trips (Cont'd)

- November 30, 1982: 9A and 9G mines, Smoky River Coal Ltd., Grande Cache, Alberta.

In addition to mines, the following institutions were visited during the trip:

- Institute of Sedimentology and Petroleum Geology, G.S.C., Calgary;
- Energy Resources Conservation Board of Alberta, Calgary;
- Coal Mining Research Centre, Edmonton;
- Alberta Research Council, Edmonton.

4.0 ROCK CLASSIFICATION SYSTEMS

4.0 ROCK CLASSIFICATION SYSTEMS

As an initial step in the study, a review was carried out of literature on the subject of rock classification systems. The search was conducted through various information retrieval systems, including the following:

CANMET, Energy Mines & Resources Canada: Mintec Data Base
National Research Council, Canada: International Energy Agency Coal Data Base
Geological Survey of Canada: Georef Data Base.

Other sources of information included:

Canadian Institution of Mining and Metallurgy
Commonwealth Scientific and Industrial Research Organization, Australia.

Rock classification systems were originally developed to assist in the design of permanent openings such as tunnels for railroads and highways, underground excavations for hydro-electric projects (penstocks, power houses) and other purposes, generally of a civil engineering nature. Subsequently, some systems were adapted to the needs of coal mining, which in turn led to the development of systems specifically for coal mine design purposes. In these systems, recognition is given to the temporary nature of coal mine openings, which range from main travel and ventilation tunnels that must last the life of the mine to extraction openings that may be required to cave immediately upon removal of the coal.

A brief description is given below of earlier rock classification systems and of subsequent ones developed for roof and floor rocks in coal mining applications. This constitutes a summary of the state of the art and provides the background to the development of a Canadian classification system.

The references quoted will be found in Appendix B of this report. Appendix C1 (Selected Bibliography) contains a list of publications and articles used in the course of the study but not referenced in the text and Appendix C2 (General Bibliography) lists other useful publications on geotechnical and mining aspects of the subject.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.1 General Rock Classification Systems

One of the earliest rock classification systems was devised by K. Terzaghi (Ref. 1). He proposed a range of seven qualitative descriptions of different rock types from "hard, intact" to "gravel and sand", taking into account features such as squeezing and swelling. For each classification he listed appropriate support systems.

Subsequent classification systems refined these principles and the more important ones are listed below.

4.1.1 Norwegian Technical Institute Q System

The Norwegian Technical Institute (NGI) system (Ref. 2) was developed and used by N. Barton, R. Lien, J. Lunde, and others to classify rocks for civil engineering purposes. The six principal parameters were:

- Rock Quality Designation (RQD), with five qualities ranging from very poor to excellent, based on the percentage of hard sound rock 100 mm or greater in length (as in core samples).
- Joint set number; nine categories depending on the frequency of joint sets.
- Joint roughness number; nine categories from discontinuous to slickensided or planar and depending on rock wall contact.
- Joint alteration number; sixteen categories ranging from tight impermeable fillings to thick continuous zones or bands of clay.
- Joint water reduction factor; six categories from dry excavations to exceptionally high inflow (e.g., pressures of over 10 kg/cm^2).
- Stress reduction factor; sixteen categories of stress from multiple weakness zones to heavy swelling rock pressure.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.1.2 Geomechanics Classification

The Geomechanics Classification of jointed rock masses (Ref. 3) was developed by Bienawski to determine rock mass classes from which average stand-up times could be determined for given spans. Five classes were developed with stand-up times ranging from 10 years for a 5 m span to 10 minutes for a 0.5 m span.

Parameters considered included point load strength index, uniaxial compressive strength, RQD, spacing and condition of joints and ground water inflow and pressure.

Principal applications of the system were to indicate support requirements in the design of tunnels, foundations and slopes.

4.1.3 Deere's Classification System

This system was developed by D.V. Deere et al (Ref. 4) as a relatively simple approach based on the RQD of the rock mass and the excavation method employed. It provides for categories of support ranging from no lining (unless there is spalling or popping) to extreme cases where yielding supports may be required.

4.1.4 R. Linder and H. Lauffer

Following the behaviour of tunnels and main pit roadways under various rock conditions led Linder and Lauffer to a classification of rocks (Ref. 5) based on the required duration of the roadway and the thickness of shotcrete needed to provide that duration. Seven classes were defined based on descriptions ranging from highly compact unfractured rocks to weathered rocks or rock debris.

4.1.5 I. Hansagi

Based on experience and tests at the iron ore mines of Kiruna, Sweden, Hansagi developed a classification system (Ref. 5) indicating support requirements for rocks in five categories according to the strata strengths. These ranged from less than 5 MPa to over 35 MPa.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.2 Roof Rock Classification Systems

For use in the design of supports for coal mine openings, separate systems have been developed in the past to classify roof rocks and floor rocks. The following systems refer to the classification of roof rocks.

4.2.1 B.N. Whittaker and A.S. Batchelor

To assist in planning for maintenance of roadways in the zones of stress concentration ahead of longwall faces, Whittaker and Batchelor developed a rock strength index ranging from 1 to 5 (Ref. 5). This was based on observation of and experiments on rocks with compressive strengths ranging from over 105 MPa to below 7 MPa.

This scale was related to the convergence rate of gate roadways with arch supports.

4.2.2 E.T. Proyavkin et al.

Proyavkin (Ref. 6) developed a scale of 26 categories of roof rocks based on qualitative descriptions of geological features in the Donetz coal basin of the U.S.S.R. These ranged from the weakest roofs that fell immediately on exposure of only a small area to the strongest that required artificial loosening (such as blasting) to induce caving.

4.2.3 W.T. Davidyanc

Davidyanc (Ref. 7) classified roof rocks in the Donetz Basin according to caving capacity in longwall faces over a standard length of over 60 to 80 m. A qualitative description is given of each type of roof rock and a corresponding empirical equation is given for subsidence at the face. Five classes are listed covering the same range as Proyavkin.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.2.4 B.S. Vinokur

In the Kizielov Coalfield in the U.S.S.R., a method known as rope-sawing is used to undercut the coal in thin pitching seams. Vinokur listed four classes of roof (Ref. 8) and developed an empirical relationship between the extracted area and the time of roof stability in each class. Roof areas ranged from 120 to 150 m^2 in the first class to 350 to 400 m^2 in the fourth.

4.2.5 R.E. Dasko and J.F. Kusnetzov

Dasko and Kusnetzov (Ref. 5) investigated caving properties of roof rocks of the Leningrad bituminous shale deposit (U.S.S.R.). Thicknesses of roof rocks susceptible to caving were related to the widths of rooms and roadways.

Also at the WNIMI Institute in Leningrad, a roof rock classification was developed for the Kuznetz Basin of the U.S.S.R. relating the distance over which the roof would remain stable to the time elapsed following the cutting pass of the coal shearer.

4.2.6 S.T. Kusnetzov and I.N. Voronin

The classification developed by Kusnetzov and Voronin (Ref. 9) was based on extensive research into the genetic features of sedimentary rocks and their propensity for caving. Point load testing of drill cores was performed in a portable press, and petrographic analysis was made of the fracture planes. Roof breakability was related graphically to the grouping or bunching of fracture planes.

4.2.7 K. Pawlowicz

At the Central Mining Institute in Katowice, Poland, Pawlowicz developed the first quantitative classification of roof rocks (Ref. 10), based on the average frequency of naturally-occurring bedding planes.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.2.7 K. Pawlowicz (Cont'd)

A roof index (L) was calculated from the average compressive strength of rocks from core samples and the average thickness of layers. Five classes of roof were defined, with values of L from 0 for the weakest to more than 130 for the strongest.

4.2.8 A. Bilinski et al.

Further work carried out at the Central Mining Institute (Ref. 11) modified and improved the roof index described in Section 4.2.7 by using the compressive strengths of rocks in rock masses rather than in cores and applying corrective factors for scale (according to rock type), and the weakening of rock with time and humidity respectively.

4.2.9 Bed Separation Resistance

A. Kidybinski, of the Central Mining Institute and co-author of this report, developed a classification of roof rocks according to their resistance to separation under the force of gravity (Refs. 12, 13). Tests were carried out on numerical models using finite element analysis, to define four zones of progressive roof failure over a longwall face: undisturbed rock over the solid portion of the coal seam, initial fracturing, partial loosening, and full loosening. For each of these zones, the bed separation resistance was determined quantitatively and qualitatively and confirmed by geophysical measurements (W. Sikora, H. Linowski, A. Kidybinski).

It was also found that there were three main levels of roof behaviour above the immediate coal seam: falling roof from 0 to 0.5 M above the longwall face; fractured roof from 0.5 M to 1.5 M; and compact roof from 1.5 M to about 3.0 M, where M was the thickness of the seam being mined. Roof support requirements were designed according to this information.

4.2.10 L. Siska

Siska (Ref. 5) developed principles for classifying roof rocks in the Ostrava - Karvina Coalfield in Czechoslovakia where hard sandstone beds proved difficult to break with longwall mining

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.2.10 L. Siska (Cont'd)

methods. The classification is based on the average length of pieces of drill core (5 to 10 cm in diameter) and covers the following categories of roof:

I - rock that caves easily (core pieces less than 7.5 cm)

II - rock that caves evenly, possibly after a short delay (core pieces 7.5 to 10.5 cm)

III - rock that caves only with difficulty (core pieces over 10.5 cm)

From this classification, graphs have been developed to assist in determining the required load bearing capacity of roof supports.

4.2.11 China Coal Society

To assist in the determination of setting load and yield load for face support, the China Coal Society has developed a classification system (Ref. 14) based on observations and analysis of statistical data from about 100 working faces in major Mining Administrations. Three important parameters in evaluating roof stability are the uniaxial compressive strength of the rock, the development of joints, and the thickness of individual strata. A distinction is made between the immediate roof (overlying the coal seam) and the main roof above it and rock classifications are developed for each, with corresponding rock strength indices that are determined quantitatively. Immediate roof categories are classified as unstable, moderately stable, stable, or hard. Behaviour of the main roof is classified as unnoticeable, noticeable, intensive, or extremely intensive.

These classifications are then used to determine support requirements.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.2.12 A.A. Orlov

In order to determine roof quality and hence the likelihood of falls, Orlov developed a classification (Ref. 5) based on observations of the extent of failure, displacement and crumbling of blocks of roof rock. He defined four categories:

- Good: even roofs without failures or displacements
- Average: roofs with stepped profiles but without falls of loose rock
- Weak: roofs with falls of loose rock, with influence of vertical fractures
- Very weak: roofs with falls of all kinds and sizes, and development of cavities in the roof.

4.2.13 A. Kidybinski

From systematic tests at over 100 longwall faces in the Upper Silesian Coalfield, Kidybinski (Ref. 5) found that roof quality could be classified on the basis of readings taken with a (Smidt) rebound hammer. The rebound number calculated from many individual measuring impacts showed a correlation with a roof quality index for determining the maximum safe exposed surface area, the average volume of falls of loose rock and the required density of supports at the face.

Diagrams have been prepared to permit prediction of roof conditions at longwall faces from the measurements obtained with the rebound hammer, and parameters have been established for evaluating the hazard of falls of loose rock. (Ref. 15).

4.2.14 E. Krippner

Krippner carried out statistical analyses of falls of loose rock at longwall faces in the Ruhr Coalfield and developed a classification system for rock sensitivity to fall (Ref. 16). It related the roof fall area to the width of the ribside path (between the face supports and the face itself).

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.2.14 E. Krippner (Cont'd)

With a path 1 m wide, a rockfall of height 1 m was classified (F) as 100%. Three main categories were established:

- Low sensitivity to fall, F less than 10%
- Medium sensitivity, F between 10% and 30%
- High sensitivity, F greater than 30%

The results were depicted graphically.

4.3 Floor Rock Classification Systems

Roadway maintenance and the proper support of longwall equipment at the face (e.g., shield supports) are directly related to the bearing capacity of rocks forming the floor of coal mine openings. A weak floor allows penetration by the supports, thereby causing a reduction in roof support.

Water in the mine and humidity in mine air affect the ability of floor rocks to support mobile equipment as well as their resistance to roof supports.

Classification systems have therefore been developed specifically for floor rocks.

4.3.1 E. Skutta

From experiments made in the Ruhr Coalfield, Skutta (Ref. 5) developed a method for testing and classifying rock based on its deterioration or degradation following immersion in water for periods of 1/2 hour, 4 hours and 48 hours respectively.

Eight classes were listed (A to H inclusive), and the appropriate letter was assigned to each time interval. For example, a rock classified AAA would show high resistance to water and unaffected carrying capacity even after prolonged immersion. One classified ACH would lose its carrying capacity completely after prolonged immersion and change into a soft material, such as clay.

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.3.2 M.B. Dusseault and H. Soderberg

In the course of a study into the post-reclamation subsidence of strip mine spoil in Alberta (Ref. 17), Dusseault and Soderberg developed a swell/slake qualitative scale based on the behaviour of rocks following immersion tests somewhat similar to those described in Section 4.3.1. Both static and dynamic tests were performed and a classification table was derived from the results.

Slaking was classified into eight categories (and sub-categories) according to the degree of deterioration and disintegration. Swelling behaviour was divided into five categories ranging from none (no increase in volume) to very high (at least a doubling of volume).

This classification was not developed for underground support purposes but it does illustrate how the propensity of rocks for slaking and swelling can be measured.

4.3.3 J.D. Jenkins and R.D. Lee

The resistance of a given area of floor rocks to the penetration of plates is not a constant value for a given type of rock but often depends on a scale factor. Jenkins examined this problem and derived an equation relating the critical floor load and the diameter of the foot plate. In addition to the diameter of the plate it included coefficients for the strength of the floor rocks and the distribution of stresses under the plate.

Lee, after making tests in mines, determined the range of parameters for Jenkins' equation for typical clayey shales and siltstones (Ref. 5).

Many investigators in a number of countries developed empirical determinations of the bearing capacity of floor rocks (Ref. 5):

- A. Stassen, A. Hausman, P. Liegeoi (Belgium)
- I.L. Davidovic, J.A. Zakutski (U.S.S.R.)

4.0 ROCK CLASSIFICATION SYSTEMS (Cont'd)

4.3.3 J.D. Jenkins and R.D. Lee (Cont'd)

- M. Hermes (Holland)
- J. Jahns (German Federal Republic)
- A.J. Barry, O.B. Nair (U.S.A.)

Most of these tests were carried out with various plate surface areas so that it was possible to relate variations in the unit bearing capacity of different rocks to the increase in surface area.

4.3.4 M. Borecki and A. Kidybinski

Borecki and Kidybinski developed a classification of floor rocks according to their bearing capacity, p_k (Ref. 5). It included three classes as follows:

I : high capacity floors, p_k over 26 MPa

II : medium capacity floors, p_k = 6.5 to 26 MPa

III : low capacity floors, p_k less than 6.5 MPa

4.3.5 R. Smieja and J. Skorka

Further tests in this field allowed Smieja and Skorka to develop a more detailed classification (Ref. 5):

1. Very strong floors (p_k over 23.9 MPa)
2. Strong floors (p_k between 19.3 and 23.9 MPa)
3. Compact floors (p_k between 13.6 ad 19.3 MPa)
4. Medium-compact floors (p_k between 6.8 and 13.6 MPa)
5. Soft floors (p_k between 3.4 and 6.8 MPa)
6. Very soft floors (p_k below 3.4 MPa)

5.0 GEOLOGY OF CANADIAN COALFIELDS

5.0 GEOLOGY OF CANADIAN COALFIELDS

Of the many coal bearing regions in Canada, only those where significant tonnages of coal are produced by underground methods have been considered in this study. These are, from east to west: the Maritimes region, where the Sydney Coalfield in Nova Scotia is of major importance, and the Plains, Foothills, and Mountain regions of Alberta and British Colombia.

The locations of current Canadian coal mines and their regional geology are shown on the map "Canada-Coal" published in 1982 by Energy, Mines and Resources Canada. A copy will be found in Appendix D.

5.1 The Coalfields of Nova Scotia

The principal coalfields of Nova Scotia occur in the Cumberland basin at the head of the Bay of Fundy, and along the east coast of Cape Breton. The Cumberland basin includes the Springhill and Joggins Coalfields. A further significant but now inactive coalfield is the Pictou, on the south shore of Northumberland Sound. The principal field, however, from which over 2.5 million tons were mined in 1981, is the Sydney Coalfield that extends off-shore from Cape Breton and is now exploited by three major underground mines. A fourth mine, the Donkin, is due to begin production in 1985 at a capacity of 3 million tonnes per annum.

The following description relates largely to the Sydney Coalfield.

The coal is of Pennsylvanian age and occurs as multiple seams. Twelve major seams exist with thicknesses most commonly between 1 and 2 metres. It is high volatile bituminous in rank.

The coal measures of the Sydney Coalfield have been deformed into a series of broad, gentle folds some 12 miles apart that plunge to the northeast. The axial traces of the folds tend to fan outwards offshore. These open folds are in marked contrast with the intense deformation of the Canadian Cordillera. Major faulting occurs along northwesterly trends. Within the principal reserve blocks, the seams are disturbed only by minor

5.0 GEOLOGY OF CANADIAN COALFIELDS (Cont'd)

5.1 The Coalfields of Nova Scotia (Cont'd)

faults and there is no interstratal slippage as seen in the Cordillera. The dip of the exploited strata varies from 4 to 10 degrees. The cleat systems and primary sedimentary structures are intact.

Apart from major fault systems that define the main reserve blocks, the principal factors that affect stability in the Sydney Coalfield are largely of sedimentary origin. The enclosing Pictou group strata consist primarily of silty and carbonaceous shales, sandstones and lenticular conglomerates. Where shales and/or mudstones overlie the coal seams, they tend to be incompetent and spall, particularly where the rock is parted with carbonaceous fossil material. Roof stability is particularly bad where sandstone channels meander through the coal measures. Differential compaction where the sandstones pinch out into a more argillaceous facies has resulted in more intensely fractured zones that are particularly susceptible to roof falls.

5.2 The Plains Region of Alberta

The Plains Region encompasses a broad arc of coal-bearing strata extending over a wide zone from Medicine Hat in the south, 750 km northwestwards, almost to Grande Prairie in the north. Numerous open pit mines are operating in the region and a number of underground mines operated formerly in the Drumheller area. The potential for underground coal exploitation is excellent however, with 17 billion tonnes alone existing in the central Ardley coal zone, and a number of properties are currently being investigated with a view to underground development.

The coal is of Upper Cretaceous to Tertiary age and ranks from high volatile bituminous in the southern Lethbridge area to sub-bituminous over most of the Plains of Alberta. The thickness of the coal varies between 1.5 and 3.0 m. Coal normally occurs in single economically-exploitable seams, as contrasted with the multiple seams of the Mountain Region. It is low in gas but is susceptible to spontaneous combustion. The coal commonly carries interlaminated seams of bentonite.

5.0 GEOLOGY OF CANADIAN COALFIELDS (Cont'd)

5.2 The Plains Region of Alberta (Cont'd)

The coal seams of the Plains Region occur on the eastern flank of a broad basin trending northwesterly. The structural geology of the area shows little tectonic disturbance, most of the seams occurring as very gently dipping structures with only broad scale folding and very minor normal faulting. In contrast to the Mountain Region, there has been no appreciable interstratal slippage and the coal has thereby retained its cleat.

The physical properties of the adjacent strata are highly variable. The roof rocks are normally shale, immediately overlain by sandstones, siltstones or minor mudstones.

Unconfined compressive strengths range usually between 0 and 50 MPa for the roof rocks. The floor rocks are generally weaker, ranging from 10 to 15 MPa. One of the distinctive features of the adjacent strata is the high content of clay minerals, notably montmorillonite. It may comprise 75% of the roof rock strata resulting in low strength and elastic properties, particularly where moisture contents are high.

5.3 The Foothills Region of British Columbia and Alberta

This coal-bearing region extends from the U.S. border for a distance of over 800 km to the northwest. For the purposes of this report, the division between the Foothills and Mountain Regions has been taken at the approximate change from high volatile to low volatile bituminous coal rank. At the present time, only one open pit is operating in the region (Luscar-Sterco at Coal Valley).

The characteristics of the coal-bearing sequence are transitional between the Mountain and Plains regions. The coals occur as multiple seams (although less so than in the Mountains) and range from Lower to Upper Cretaceous in age. The rank of the coal is high volatile bituminous.

5.0 GEOLOGY OF CANADIAN COALFIELDS (Cont'd)

5.3 The Foothills Region of British Columbia and Alberta (Cont'd)

The coal-bearing sequence is exposed along a series of northwest-trending fault blocks and associated folds. The thrust planes dip westerly, generally at low angles. The structurally incompetent coal-bearing sequence is faulted and in places strongly folded where the strata are in proximity to the strike of major structural features.

The coal seams are less gassy (approx. 1 cu.m. per tonne) than those of the Mountain Region; however they are very susceptible to spontaneous combustion. The roof and floor strata, comprising sandstones, siltstones and mudstones, display higher unconfined compressive strengths than in the Plains Region but do not display the intense shearing and bedding plane slippage of the Mountain Region strata. In this respect, the roof strata of the Foothills Region are generally better for support than those of the neighboring regions. The unconfined compressive strengths of the roof sandstones range from 80 to 120 MPa, and are somewhat less for the siltstones and mudstones. The roof rocks may also contain substantial proportions of bentonite clays.

5.4 The Mountain Region

This coal-bearing region is entirely within the Rocky Mountains and extends northwestwards from the U.S. border for a distance of some 900 km through Western Alberta into northeastern British Columbia. The region attains a width of up to 50 km. Eight mines are currently operating, of which two have underground operations (B.C. Coal - Michel and McIntyre Mines - Smoky River). Numerous underground mines have previously been operated in the region.

The coal occurs as multiple seams and is predominantly Lower Cretaceous in age. It ranges from low-volatile bituminous to semi-anthracite in rank.

5.0 GEOLOGY OF CANADIAN COALFIELDS (Cont'd)

5.4 The Mountain Region (Cont'd)

The Mountain Region has been highly deformed with the coal measures occurring within folds between thrust sheets of older Palaeozoic rocks. This is exemplified by the synclinal Crowsnest Coalfield that is bounded on the west by the Elk River thrust sheet. As a result, the coal seams are commonly folded, sheared and faulted at all scales.

The individual coal seams may attain considerable thickness, often due to tectonic squeezing towards the axial zone of folds. Bedding plane slippage is thus apparent both in seams and in adjacent strata. Due to this shear action, the coal is very friable, slickensided and without cleat. It is also high in gases (methane, carbon dioxide and nitrogen), containing more than 10 cubic metres per tonne at depth. As a result, the rocks are susceptible to bursting, usually related to structural anomalies, and there has been a history of severe outbursting both in the Canmore and Crowsnest areas.

The rocks overlying the coal seams are generally of an argillaceous nature with mudstones, shales or siltstones immediately above the coal and sandstones within a few metres of this interface. The overlying sequence is generally of stronger materials than elsewhere; however tectonic disturbance (fracturing, bedding-plane, shearing, etc.) can significantly reduce their self supporting capacity.

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS

In order to examine and illustrate the variations in properties of roof and floor rocks in Canadian coalfields, a series of visits was made to underground mines.

During these visits some preliminary tests of rock strengths were made through the use of a Smidt rebound hammer, with the results being analysed and plotted graphically to determine quantitatively two of the more important properties:

- The "bed separation resistance" (BSR) of roof rocks
- The "load bearing capacity" (LBC) of floor rocks

These terms are defined in Chapter 10.0 and the graphical determinations appear in Appendix A to this report. BSR and LBC were determined from rebound hammer readings in accordance with the procedure developed by Kidybinski (Ref. 15). Where site visits and direct measurements were not possible, hypothetical results, based on previous experience and such information as was available, have been plotted for illustrative purposes.

From observations made during the mine visits and from a review of literature on the subject, it is evident that there are wide variations in geotechnical properties of roof and floor rocks from one major coalfield to another, from mine to mine within a coalfield and indeed from one place to another in the same mine or seam. The observations made and results obtained from tests during the visits are therefore very site-specific and should not be interpreted as typical of the coalfield. The more general properties have been described in Chapter 5.0 and may again be referred to in relation to the specific mines listed below.

6.1 Maritimes

The Sydney Coalfield is the largest and most important coalfield in the Maritimes and in 1980 an extended visit was made to the Cape Breton Development Corporation's Prince Mine, at Point Aconi. During this visit numerous tests were made of roof and floor rocks in order to determine their geotechnical properties and thence make recommendations for powered supports

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS (Cont'd)

6.1 Maritimes (Cont'd)

and roadway maintenance in the mine. The results of the study and subsequent recommendations are described in an internal report to CBDC by A. Kidybinski and J. Gwiazda (Ref. 18).

In the Point Aconi area, the Hub Seam is 2.3 m thick. It is both overlain and underlain by weak shales whose thickness varies considerably from one part of the mine to another (compare Figures A1, A2). From the graphs it can be seen that the roof shales show very little resistance to bed separation and cave easily. The shales in the immediate floor are also weak as shown by the low load-bearing capacity. They are also highly susceptible to slaking by any water entering the mine which dramatically reduces their load-bearing capability, both for mine support (e.g., steel arches) and for rubber-tired vehicles. Analysis has shown the presence of smectite and a low quartz content to be significant features in this regard.

Though the mines presently operating in the Sydney Coalfield (Prince, Lingan, No. 26) are all submarine operations, they are generally dry due not only to the undisturbed nature of the coalfield and the longwall mining method adopted to allow even settlement of the ocean floor but also to the substantial depth of cover in most areas.

The nominal roof strata in the Sydney Coalfield are siltstones, mudstones and shales (Ref. 19). In some areas (noticeably at No.26 Colliery) sandstone intrusions have occurred in the immediate roof of the coal seam (the Harbour seam is currently the only one mined at No. 26). These result in roof collapse at the longwall face. Detailed examination and mapping of these "intrusions" have shown that they are probably infilled paleo river channels whose general direction can be predicted. This information is used in mine planning.

The sandstone channels also have an effect on the floor rocks where undulations or rolls with gradients of up to 25° (compared with the normal dips of 5° to 10°) have been recorded in the seam floor. These correspond to the deepest point of ero-

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS (Cont'd)

6.1 Maritimes (Cont'd)

sion of the channel above. The rapid increase in dip over a distance of 5 to 10 m causes difficulties for the longwall support systems.

Floor rocks in the Sydney Coalfield can vary in hardness due to the presence of "seatearths", the occurrence of fossil soils beneath the coal seams. These soils are highly variable in composition, ranging from mudstones with a high proportion of plant rootlets (resulting in soft floor zones to the Harbour seam at Lingan Colliery) to quartzose sandstones containing a high proportion of silt (giving rise to some very hard floor sections for the same seam at the adjacent No. 26 Colliery). This hard floor forms a good working base but constitutes a hazard because of the tendency to generate sparks when struck by cutter picks.

It is of interest to note that CBDC has used a classification of rocks based on the porportion of quartz grains over 5 microns in diameter as a guide to the "incendive temperature potential" - the tendency to generate sparks.

6.2 Alberta Plains

In the course of carrying out this project, it was not possible to arrange visits to any underground mines in the Plains region. The information that follows was obtained from industry and research personnel and, while somewhat generalized, does give some specific examples from different parts of the region.

In general the roof and floor rocks are somewhat softer than the sub-bituminous coals themselves, with the roof rocks being the harder of the two. This is the case at the Vulcan property of Seagull Resources Ltd. Genstar's Star Key mine, near Edmonton, though covered by shallow and loose overburden, has soft roof rock with good caving characteristics and is presently the subject of a mine planning study.

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS (Cont'd)

6.2 Alberta Plains (Cont'd)

In the Drumheller area, Century Coals, of Calgary, are operating the Atlas mine. The No. 1 Seam is 3 to 4 m thick at a depth of 130 m and roof and floor conditions are good. In another development, a seam 1.3 m thick is being opened up by Allan Menzies from an adit 4 m wide being driven in the coal. The roof is strong enough to allow the use of an Alpine Miner for excavation but subsequently requires timber support.

The Alberta Research Council (Ref. 17) has tested drill cores from the Drumheller area and found that the floor measures have a high smectite content, indicating the likelihood of severe weakening through absorption of water. Slakeability tests have been carried out to quantify this property.

In the Lethbridge area, the Galt seam has been explored from the Kipp shaft put down by Petro-Canada in collaboration with Precambrian Shield Resources. Fording Coal has carried out geotechnical studies on their property in the same area.

In the absence of rock strength tests taken in situ, some projections have been made for roof and floor rocks of the Lower Ardley "B" Seam, in the Red Deer area. These projections were made from drill cores and indicate what may be expected for the types of rock encountered in the drilling. The results, while somewhat speculative, have been plotted (Figure A3) to provide a comparison with those from other mines visited in the course of this project.

6.3 Foothills

The Coal Valley property of Luscar Sterco was visited as an example of an underground mine in the Foothills Region. Of the four seams of mineable thickness, three are presently being exploited: the uppermost (Val d'Or) by open pit, the Silkstone (Wee) by both open pit and, in a new development, by underground methods, and the lowest, the Mynheer, by open pit in its upper portion.

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS (Cont'd)

6.3 Foothills (Cont'd)

The area was worked extensively in the 1920s and 1950s and the old mine plans are being used in conjunction with current geotechnical techniques to plan the underground workings of the Silkstone seam. The roof rocks of the new workings were accessible in the portal area (in the open pit) and strength measurements were taken with the rebound hammer. There was no comparable exposure of floor rocks and the graphs drawn in Figure A4 are based on such information as was available at the mine.

The roof consists of a soft sandstone, with a pronounced system of joints that are being mapped to assist in mine planning. It is supported by rockbolts in openings up to 7 m wide. The floor is mudstone which shows marked deterioration when wet.

6.4 Rocky Mountains

The Rocky Mountains Coalfield is characterized by steeply-dipping and tectonized seams up to 15 m in thickness. Many of the areas, such as the Canmore Field near Banff and the Crowsnest Field further south, are structurally complex and difficult to mine. They are characterized by irregular pinching and swelling of seams and the cleat is often destroyed by folding, shearing, thrusting and faulting. The mines in the Canmore area were prone to outbursts and had ceased operation by the late 1960s.

In the course of this study, three underground mines were visited and in each case it was possible to gain access to the immediate roof and floor rocks of the main seams.

At the Balmer North mine of B.C. Coal, in Sparwood, B.C., access to the No. 10 Seam was gained from adits; readings of rock strengths were taken with the rebound hammer (Figure A5). The roof consists of mudstones and siltstones and the floor of mudstone and shale. Rockbolts are used for support in the

6.0 GEOTECHNICAL CONDITIONS IN CANADIAN COALFIELDS (Cont'd)

6.4 Rocky Mountains (Cont'd)

room and pillar operation. B.C. Coal also operate a hydraulic mine in the No. 10 Seam at Balmer South, where some further measurements were taken. The hydraulic operation itself was not visited.

Cardinal River Coals, at Cardinal River, Alberta, operate a number of open pits on the Jewel Seam which averages 12 to 13 m in thickness. As with most of the Rocky Mountain seams, the dip is often very steep, and at Cardinal River the Jewel varies from horizontal to almost vertical. An underground operation is planned and twin tunnels have been driven from one of the pits to provide access to the seam at depth. These tunnels intersected an almost-vertical limb of the seam and at this point it was possible to take readings on the immediate roof and floor rocks with the rebound hammer. Results are plotted in Figure A6. The coal itself is soft and falls easily. The immediate roof is a mudstone overlain by a harder sandstone. Floor rock is sandstone and a hydraulic mining operation is being considered. Roof support in the tunnels is provided by split sets and rockbolts in accordance with the recommendations of an in-house geotechnical study.

Farther north, at Grande Cache, Alberta, McIntyre Mines operate both open-pit and underground mines as Smoky River Coal Limited. The three principal seams are No. 11, No. 10 and No. 4, of which only the last is presently being mined underground. While the underground operations were visited, immediate roof and floor rocks were inaccessible for testing on account of steel sets and timber support. However rebound tests were performed on the hanging-wall and foot-wall rocks of No. 4 Seam in the open pits. These are plotted in Figure A7. In the 9A mine underground, the shale and siltstone roof of the room and pillar operations is supported with rockbolts and heavy wire screening after the rooms are opened up with Lee-Norse miners. Some experimental work is being done with grouted wooden dowels to prevent spalling of coal pillars in the No. 1 East section. Pillaring, followed by caving of the gob, is in progress in No. 1 West section. The floor rock is siltstone underlain by sandstone and, while wet in many areas, does not appear to cause any serious problems from slaking.

7.0 REQUIREMENTS OF A CANADIAN CLASSIFICATION SYSTEM

7.0 REQUIREMENTS OF A CANADIAN CLASSIFICATION SYSTEM

A brief review of geotechnical conditions existing in Canadian underground coal mines shows a wide variation in the engineering factors considered to be important for mine operation. Roof strata vary from strong but interlayered sandstones (Maritimes) through very strong but densely-fractured siltstones (Mountains) to very weak, friable and slickensided shales (Maritimes and Mountains) or soft and highly moisture-sensitive shales and sandstones (Plains and Foothills). Floor strata vary from strong sandstones and siltstones (Mountains) through medium strength shales and mudstones (Foothills, Maritimes) to soft and moisture-sensitive shales and claystones (Plains, Maritimes). The engineering properties of the coal seams may vary from highly-fractured high-rank coal (Mountains) through bituminous coal that is difficult to break (Maritimes) to low-rank bituminous hard coal and lignite (Plains).

In the Rocky Mountain and Maritimes Coalfields, one of the main hazards is from pillar instability and the high probability of roof falls, while in the Plains, floor swelling and roof slaking present the biggest problem. On account of their cleavage, some coal seams in the Mountains are best mined by hydraulic cutting, while in the Plains, coal hardness and moisture sensitivity of the rocks adjacent to the coal and the flat-lying attitude of the seams discourage the use of hydraulic mining methods. In deeper parts of the Mountain seams, coal/gas outbursts due to high gas content and fracture density create a potential hazard, while in the deeper Maritimes seams, rockbursts may occur due to the higher strength of the coal and overlying sandstones and possibly a high propensity for bursting.

The strata properties mentioned above have a direct impact on mine design and must be taken into consideration by any classification system developed for Canadian conditions.

7.0 REQUIREMENTS OF A CANADIAN CLASSIFICATION SYSTEM (Cont'd)

The examination carried out in Chapter 4.0 of existing rock classifications used both for coal mining and civil engineering purposes reveals their limited applicability in Canadian underground coal mines. Although numerous classifications are being used in various mining countries, no general classification system exists to cover all parameters of major importance. Furthermore, most of the existing roof stability classifications have been designed for single and wide openings of a permanent type, such as road or railway tunnels, and underground power stations. They are not applicable to coal mine conditions where high stress concentration factors and nearby caving zones affect roadway stability.

It should be stressed here that cheaper types of support should be used in mines than in tunnels, due to the short time the opening is used and the self-supporting ability of arched sections of the roof rock. A further need to develop cheaper support methods in underground coal mines is to enable them to remain competitive with large-scale low-cost open pit operations.

Geomechanical classifications produce recommendations only of rigid support for openings, which does not allow for the large deformations encountered in most coal mines. On the other hand, roof classifications designed for coal mining purposes deal mainly with caveability, which is a longwall parameter not applicable directly to other mining methods such as room-and-pillar. Most existing roof classifications are based on the strength of rock samples, whereas structural rock features such as bedding planes, partings, and fractures play predominant roles in roof stability, especially in the Mountain and Maritimes regions.

The most significant drawback of existing classifications of floor strata is that the effect of moisture on the load bearing capacity may not be predicted on the basis of initial strength and slakeability testing. This is of special importance for the Foothills and Plains regions and relates also to roof strata classifications.

7.0 REQUIREMENTS OF A CANADIAN CLASSIFICATION SYSTEM (Cont'd)

The main requirements of a Canadian system are therefore flexibility, to permit a uniform rating of major geotechnical parameters in all mining areas, and simplicity, so that it can function as an important tool in the design and operation of mines.

In addition to the classification system itself, appropriate testing methods are needed in order to develop the site data required for classification purposes.

8.0 PROPOSED GENERAL CLASSIFICATION SYSTEM

8.0 PROPOSED GENERAL CLASSIFICATION SYSTEM

On the basis of previous experience and the work undertaken in the course of this study, it is proposed that the roof and floor rock classifications developed in detail in Chapters 9.0 and 10.0 form part of an overall system classifying the mineability of coal seams.

The general classification system described here and on which further work has been recommended in Chapter 13.0 is based on eight major parameters affecting mineability; two pertain to the stability of roof and floor strata, and the remaining six (outburst hazard, seam continuity, stability of pillars, potential for spontaneous combustion, bursting propensity and machine workability) are properties of the coal seam itself.

Of the eight parameters, the most important in terms of mineability is the stability of roof strata; roof rocks have accordingly been divided into six classes (details are given in Table 4 at the end of Chapter 9.0). For the purpose of determining mineability of a coal seam, each class has been assigned a point rating according to its desirability. These are given in Table 1, and range from 0 to 12.

Based on their stability, floor rocks have been divided into four classes as shown in Table 5 (Chapter 10.0). They have been assigned point ratings ranging from 0 for very weak unstable rocks to 8 for strong, stable rocks offering the best mining conditions.

The remaining six parameters relating to the coal seam itself have each been divided into four classes ranging from low or poor to high or good. A weighted point rating has been assigned to each class of each parameter according to its relative importance.

The eight parameters listed above are considered as sub-classifications and are measured by appropriate testing methods, preferably carried out "in situ" if underground access to coal-bearing strata is available. Testing includes the effect of water on rock strength and the effects of scale and time.

8.0 PROPOSED GENERAL CLASSIFICATION SYSTEM (Cont'd)

Following testing to determine their classification, Table 1 is used to assign a mineability point rating to each parameter. Maximum point rating for each parameter corresponds to the most favourable mining condition, even though this may not be represented by the highest classification number.

(For example, a very strong hard stable roof rock would be categorized as Class 6 but only be assigned 8 points as such a roof is a disadvantage for most coal mining methods. On the other hand a Class 5 roof rock would be assigned 12 points. In the coal seam itself, a very low potential for spontaneous combustion (Class 1) would represent the most favourable condition and be assigned a point rating of 5.)

The sum of these point ratings gives an indication of the mineability of the seam as a whole which is classified as shown in Table 2, where five classes of mineability (A to E) have been established. A coal seam with a total point rating of 45 from Table 1 would be classified "A" in terms of overall mineability.

A general classification system such as this would be used for feasibility studies on coal seam extraction methods and for determination of the most promising areas for future exploitation.

TABLE 1 GENERAL RATING OF CLASSIFICATION PARAMETERS AFFECTING MINEABILITY

Parameter	Class					
	1	2	3	4	5	6
	Low ——— High					
	Point Rating					
Strata adjacent to coal						
Roof stability	0	2	6	10	12	8
Floor stability	0	3	5	8	-	-
Coal seam						
Outburst hazard	7	5	2	0	-	-
Seam continuity	0	2	4	6	-	-
Pillar stability	0	1	4	5	-	-
Potential for spontaneous combustion	5	3	1	0	-	-
Bursting propensity	4	3	2	0	-	-
Machine workability of coal	3	2	1	0	-	-

TABLE 2 GENERAL CLASSIFICATION SYSTEM FOR MINEABILITY OF COAL SEAM BY UNDERGROUND METHODS

Classification	Mineability of coal seam	Points
A	Mineable, very good conditions	41 - 50
B	Mineable	31 - 40
C	Mineable with technical difficulties	21 - 30
D	Mineable at high operational costs	11 - 20
E	Not mineable at present stage of technology	10 or less

9.0 CLASSIFICATION OF ROOF STRATA

9.0 CLASSIFICATION OF ROOF STRATA

When access to roof rocks is available from underground, more significant measurements can be taken and the parameters to be determined are described in Sections 9.1 and 9.2.

During the exploration stage of a mine, before access is available from underground openings, borehole cores provide the best opportunities of determining approximate characteristics of roof strata. These methods are described in Section 9.3.

9.1 Critical Roof Span

Critical roof span (CRS), proposed as a basic roof strata classification parameter, is defined as the maximum diameter of a circular or semi-circular opening in which roof strata will remain in a self-supporting, stable condition over the period of time required for mining operations. This includes the effect of convergence of surrounding pillars, roof subsidence by the gob, and the effect of rock vibration due to nearby blasting and rock tremors. For this reason, the most accurate evaluation of CRS may be made through direct underground observation at the site in question, or by testing roof rock properties by "in situ" methods, which allow assessment of the strength properties of partings, interbed planes, shear zones etc. A rough estimate of CRS by careful analysis of exploration drill core is also possible.

9.1.1 Method of Determining CRS by Increasing Spans

Direct CRS evaluation through long-lasting roof exposure may be arranged by the gradual horizontal expansion of the semicircular room diameter over a period of approximately four weeks. No permanent roof supports may be used during this experiment, but remote convergence gauges/recorders installed close to the centre of an opening would supply early warning signals of approaching roof collapse. Safety measures should be strictly observed during coal cutting operations and manpower reduced to a minimum.

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.1.1 Method of Determining CRS by Increasing Spans (Cont'd)

Operational experience from existing or dormant underground mines close to the location being analysed may offer valuable data to assess the CRS.

9.1.2 Method of Predicting CRS by Penetrometer (HBP)

The method of testing the strength of rock strata by hydraulic borehole penetrometer is suggested for general use in underground access situations. It is the only known method that gives direct roof rock strength data from "in situ" testing with special reference to the weakest planes in the roof (partings, interbed planes, joints, etc.). Parameters measured by the HBP method allow prediction of the critical roof span by simple mathematical calculations.

HBP techniques require boreholes to be drilled from underground openings into the roof strata. The diameter of the boreholes should be kept within 86 $\pm$ 10 mm (preferably 86 mm) and the length may be up to approximately 12 metres. The borehole wall should be straight and smooth and is therefore best drilled using a diamond coring bit connected to a barrel. If a stage bit is to be used, an 86 mm diameter cylindrical follower at least 0.5 m long should be fixed just behind the bit to keep the borehole straight and to prevent large variations in diameter. Boreholes should be drilled shortly before HBP testing particularly in weak and moisture-sensitive rocks. Clean water is to be used as a bit cooling agent. Boreholes should be vertical, with 10 percent tolerance. A qualified team of three HPB operators is able to test 2 or 3 boreholes of 10 m in one shift.

The hydraulic borehole penetrometer (Figure 1) uses a probe which consists of a steel housing containing an hydraulically-actuated flat-ended indenter (5 mm in diameter) with a plunger return spring. If the borehole to be tested has a diameter greater than 95 mm, a steel buckle is used as an adapter to ensure proper positioning in the borehole.

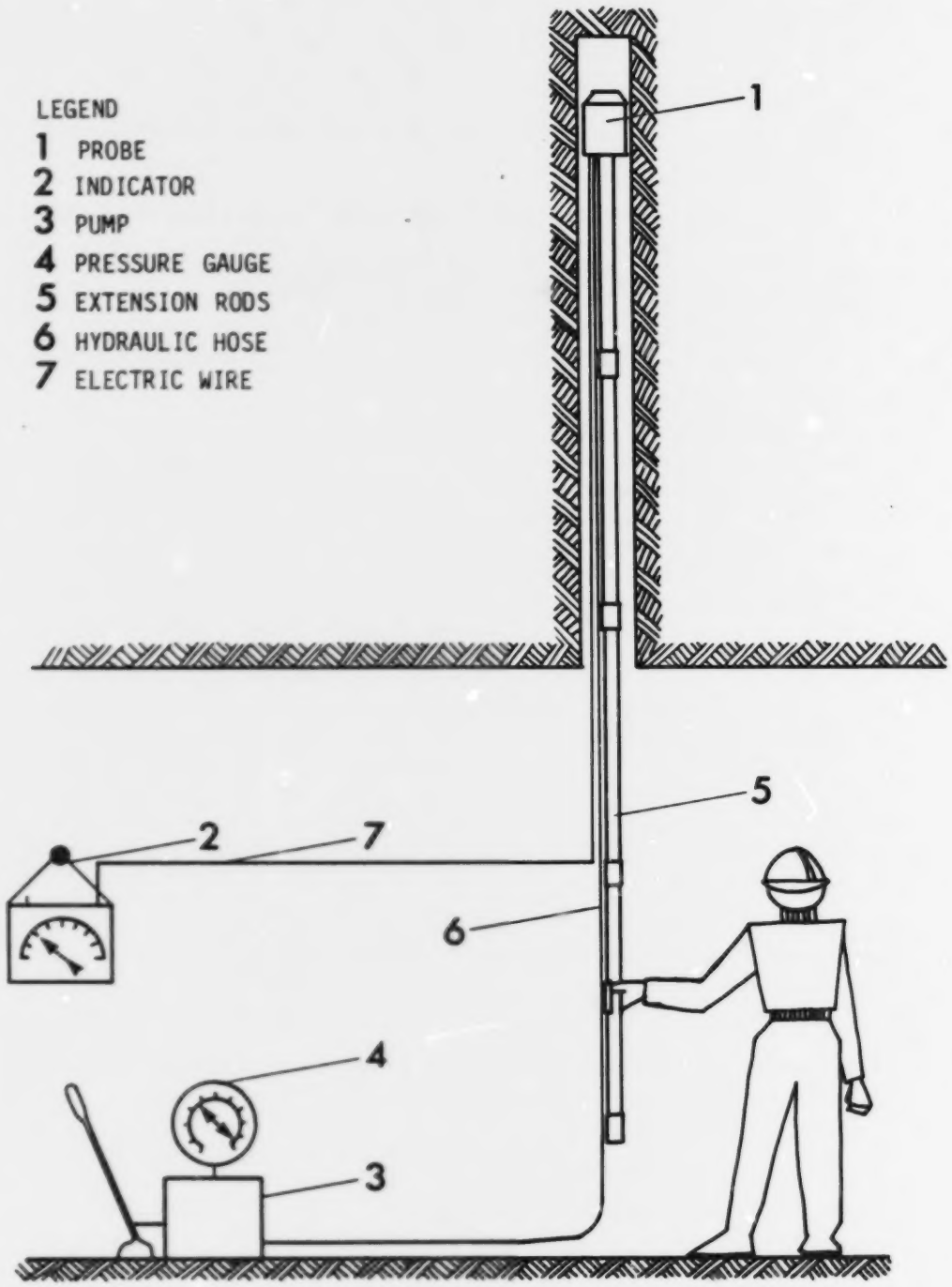


FIG. 1
ARRANGEMENT OF HYDRAULIC BOREHOLE PENETROMETER

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.1.2 Method of Predicting CRS by Penetrometer (HBP) (Cont'd)

In order to take measurements with the HBP, the probe is positioned in the borehole with the plunger against the rock layer to be tested and oil is pumped to the probe. Movement of the plunger is observed on an indicator until rock failure occurs.

This is indicated by a simultaneous fast move forward of the plunger from its stable position on the borehole wall and a rapid drop in the oil pressure. The maximum value of the oil pressure (p_m) is recorded for further calculations. A valve of the pump is opened to return oil to the reservoir and the plunger returns to its starting position within the probe. The probe is moved vertically to the next testing point, the valve is closed and oil is pumped again.

In geologically homogeneous rocks, test points are usually vertically spaced at 0.1 m, and within the immediate roof strata (up to approximately 2 metres above the seam) a spacing of 0.05 m is recommended. Weak partings, interbed planes and other places in the rock important from a geotechnical viewpoint are tested with higher precision (0.01 m vertical spacing) and by using the whole perimeter of a horizontal section of the borehole for multipie results.

Results of measurements are presented graphically by plotting values of p_m against vertical position for consecutive test points. In Figures. 2, 3, 4 and 5, practical examples are given of HBP logs applied to various operational tasks.

Three parameters essential for the calculation of critical roof span may be found from HBP logs, namely:

- bed separation resistance (BSR),
- immediate roof thickness (h), and
- roof band thickness to the first expected separation plane (t).

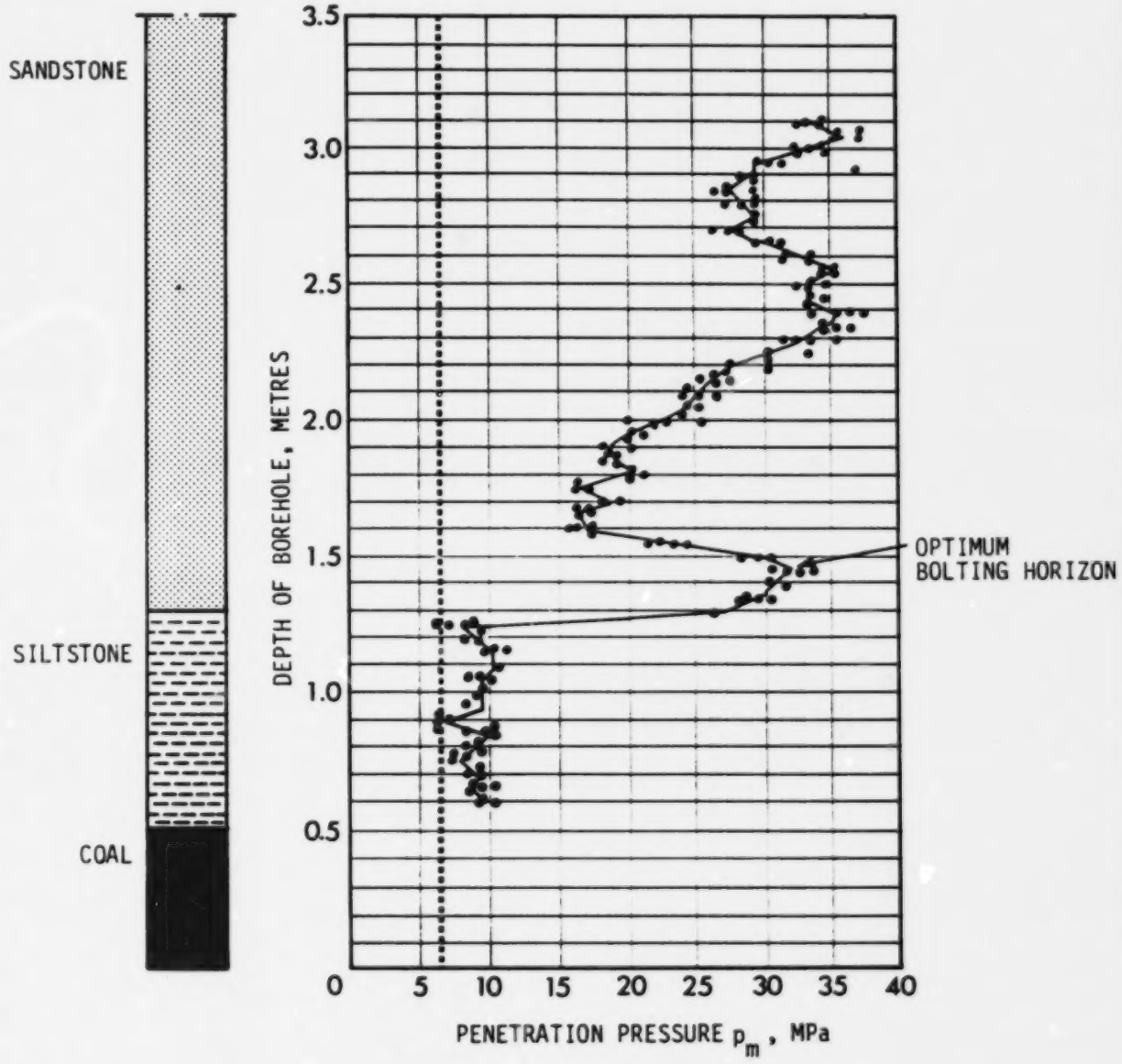


FIG. 2
LOCATION OF OPTIMUM BOLTING HORIZON IN ROOF STRATA

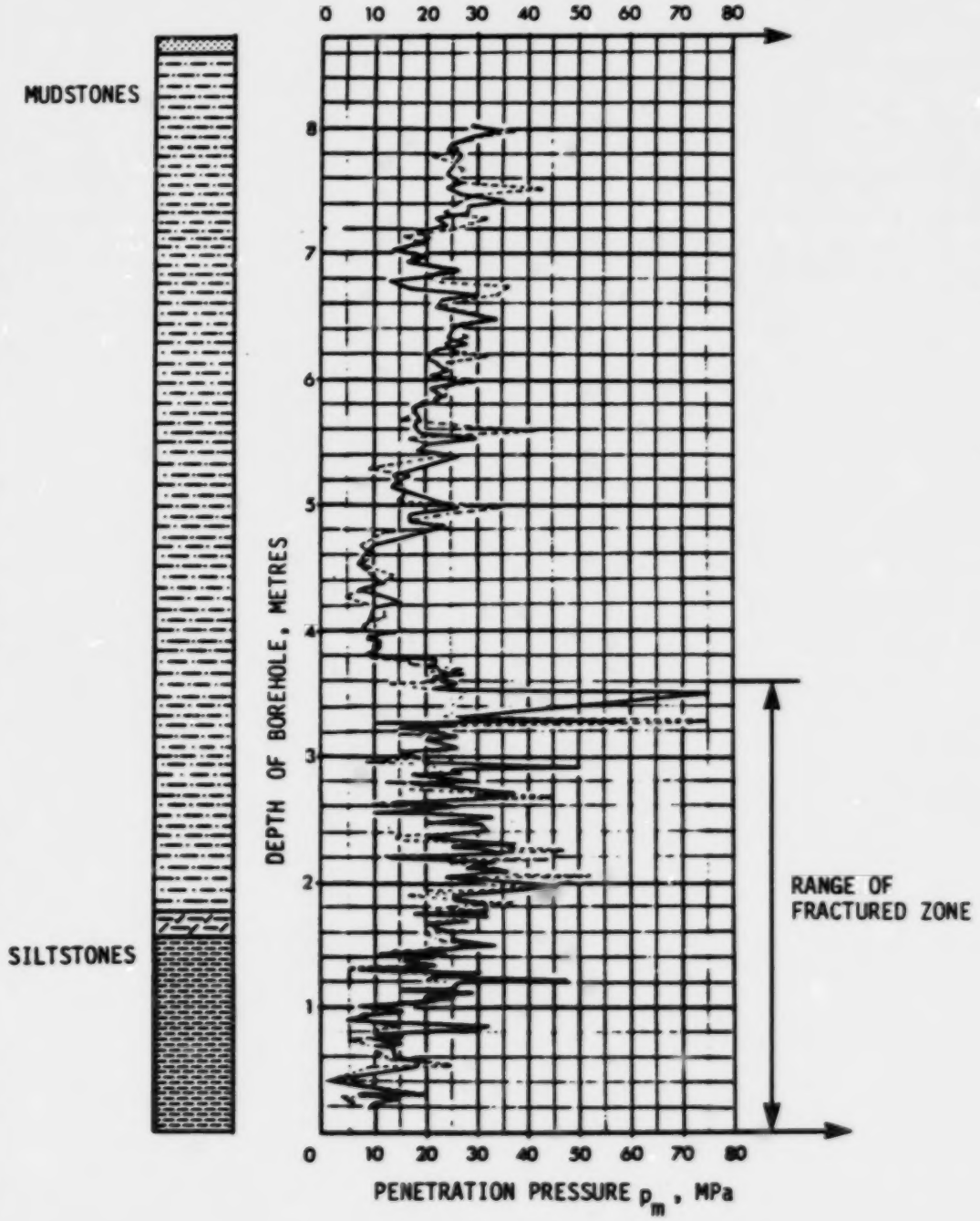


FIG. 3

DETERMINATION OF VERTICAL EXTENT OF FRACTURED ZONE IN ROOF FOR SELECTION OF ROADWAY SUPPORTS

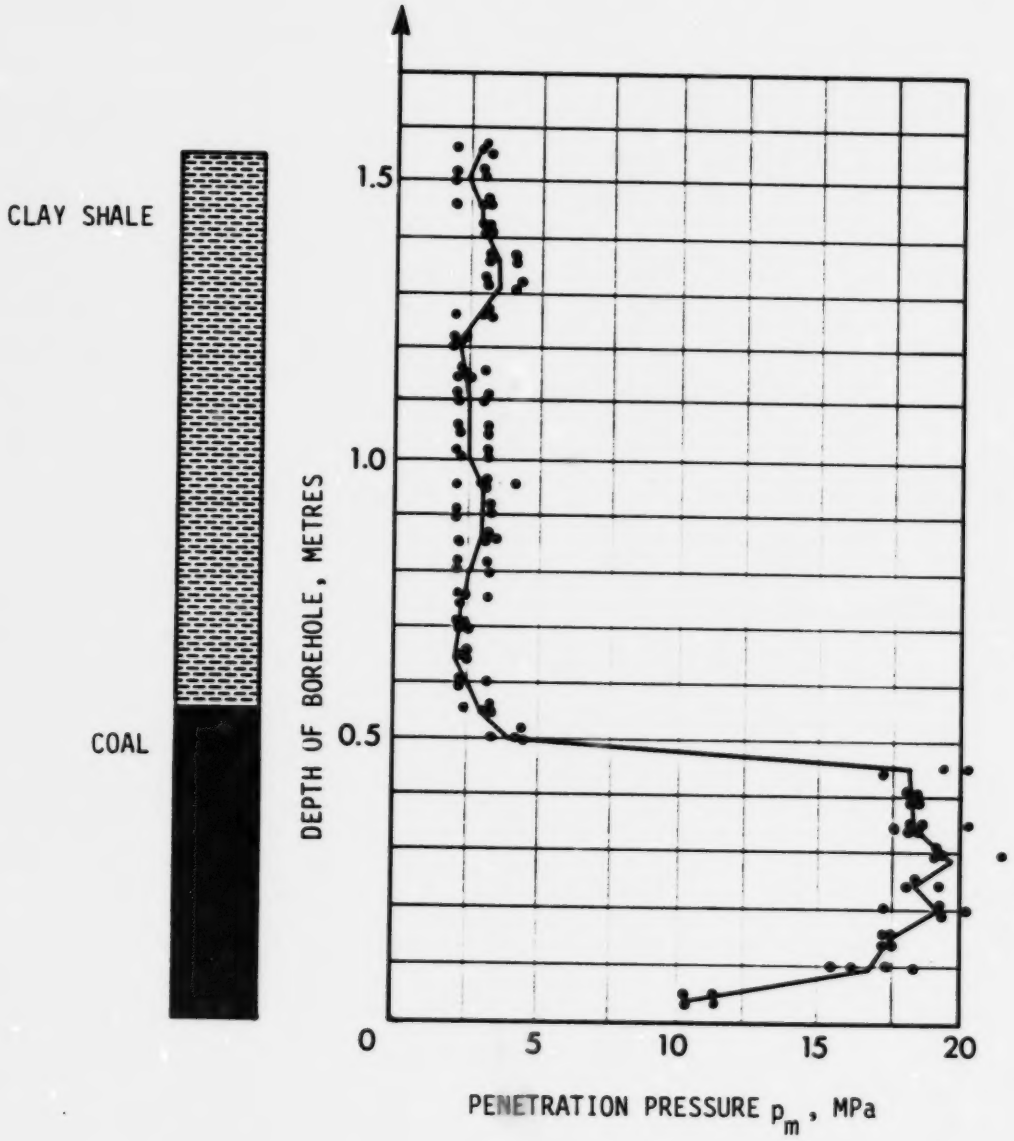


FIG. 4
DIMENSIONING OF TOP COAL UNDER VERY WEAK SHALE

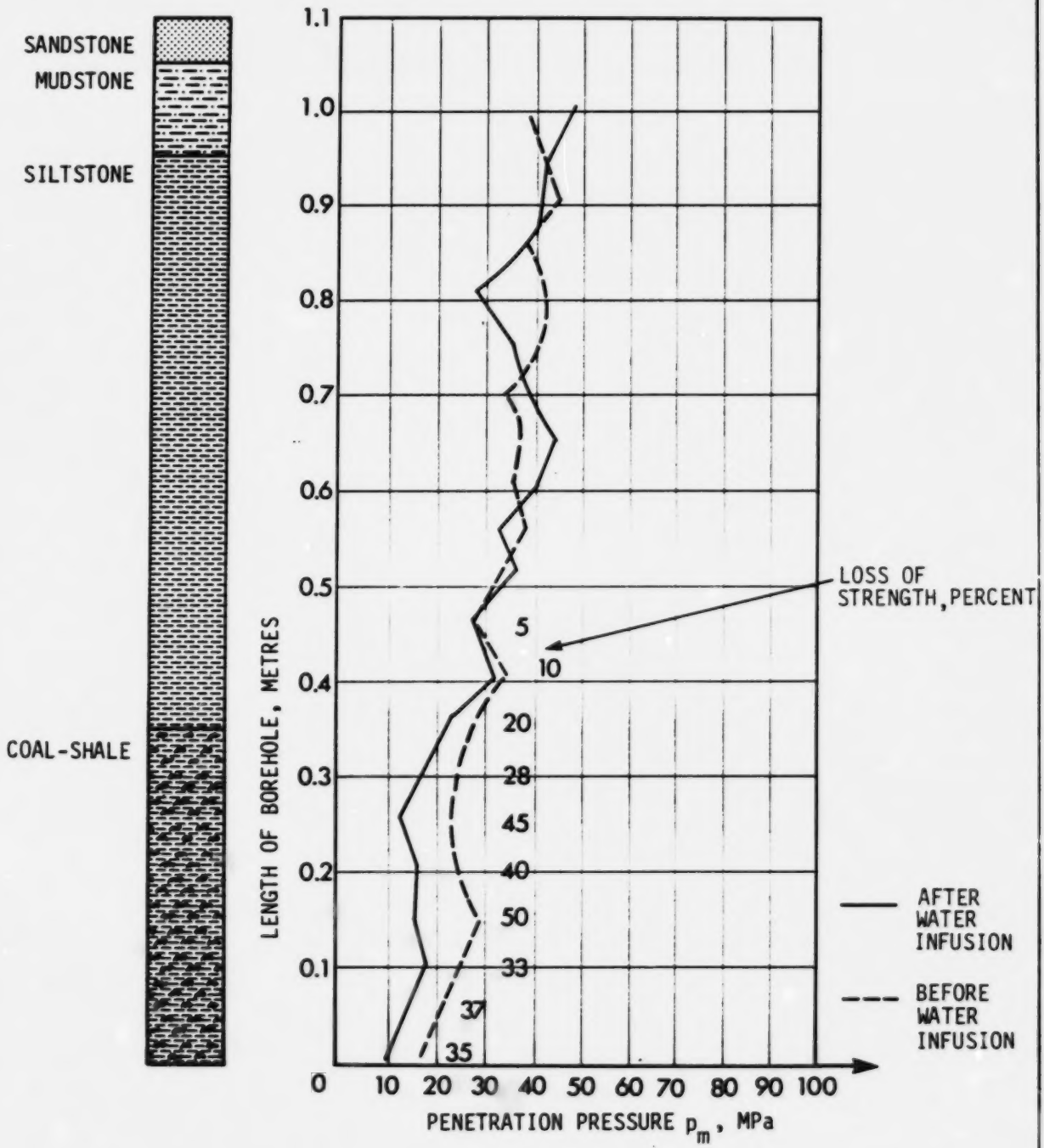


FIG. 5

PERCENTAGE REDUCTION IN ROOF STRENGTH FOLLOWING HIGH PRESSURE INFUSION OF WATER IN COAL SEAM

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.1.2 Method of Predicting CRS by Penetrometer (HBP) (Cont'd)

Bed separation resistance is defined as resistance of rock to vertical tensile stress caused by gravity (tensile strength under vertical force). Since rocks are least resistant to tensile stresses, BSR represents the most important physical feature affecting roof stability. It is related to critical oil pressure (p_m) in the HBP according to the following formula:

$$BSR = 0.077\ p_m \qquad (9.1)$$

where both BSR and p_m are in MPa.

Immediate roof thickness (h) is defined as the vertical distance from the roof of an opening to the nearest long-term self-supporting horizon. In homogeneous weak shales it extends over approximately 1.5 M (where M is the extracted thickness of the seam). In Figure 6 a method of finding BSR, h and t from an HBP log is illustrated, and in Figures 7, 8, and 9, practical examples are given from three selected coal mines.

It is evident from these figures that in practice the logs are not as easily interpreted as it would appear from the idealized version in Figure 6. A certain degree of experience and judgement is therefore required.

9.2 Rock Slakeability

In the case of water-sensitive roof strata, BSR values calculated with formula (9.1) should be multiplied by the slakeability factors (SF) of the rocks concerned, at least for an immediate roof interval.

The slakeability factor is defined as the proportion of the rock strength after long exposure to water compared to the strength of dry, freshly-exposed rock. It is related to the way a rock sample behaves when immersed in water.

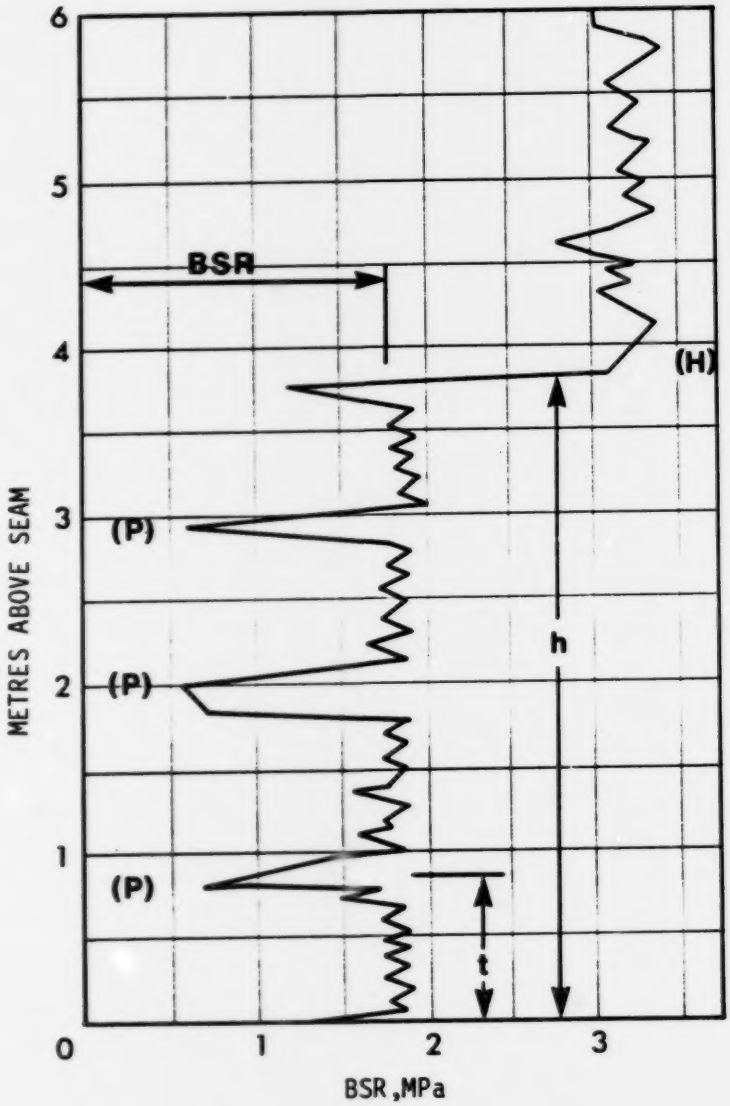


FIG. 6

ESTIMATION OF CHARACTERISICS BSR, h AND t
FROM BOREHOLE PENETROMETER LOG OF ROOF STRATA

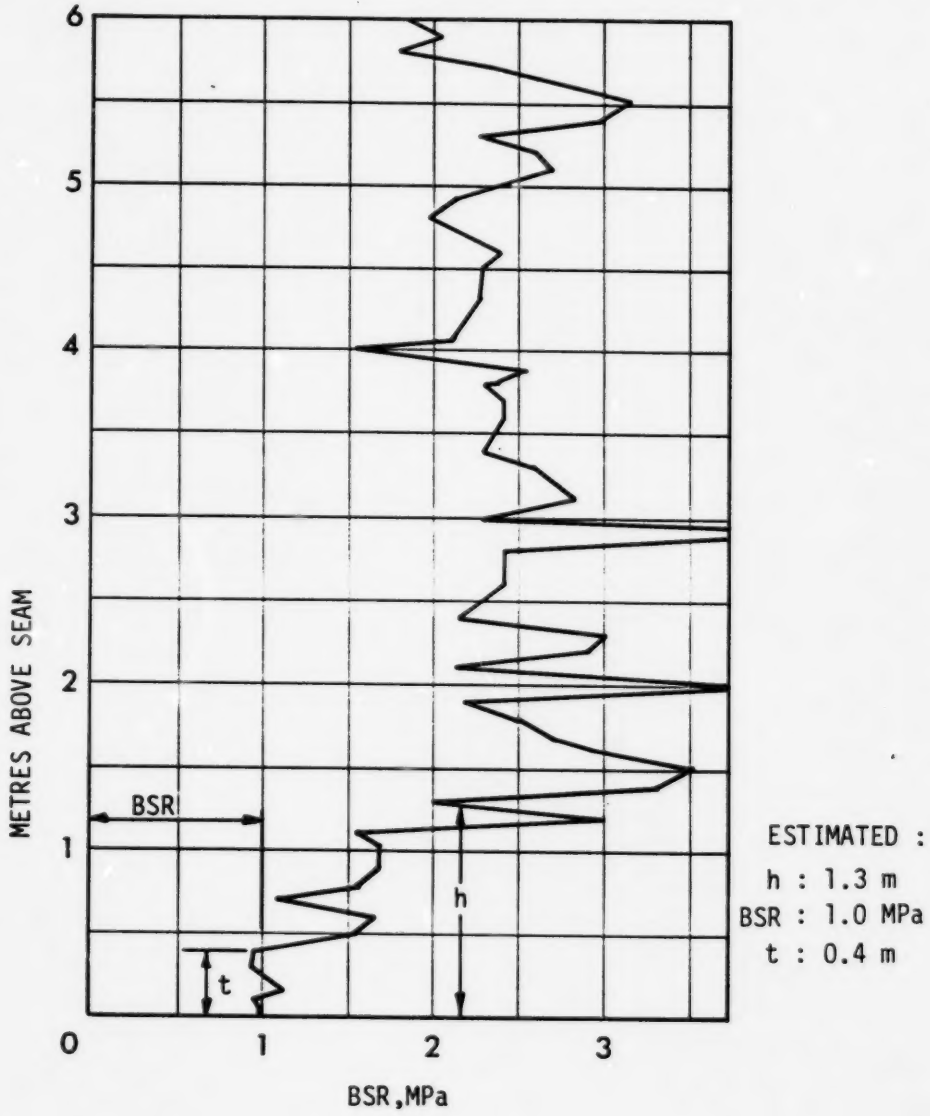


FIG. 7

LOG OF BED SEPARATION RESISTANCE (BSR)
(SEAM 405, HALEMBA MINE, UPPER SILESIA)

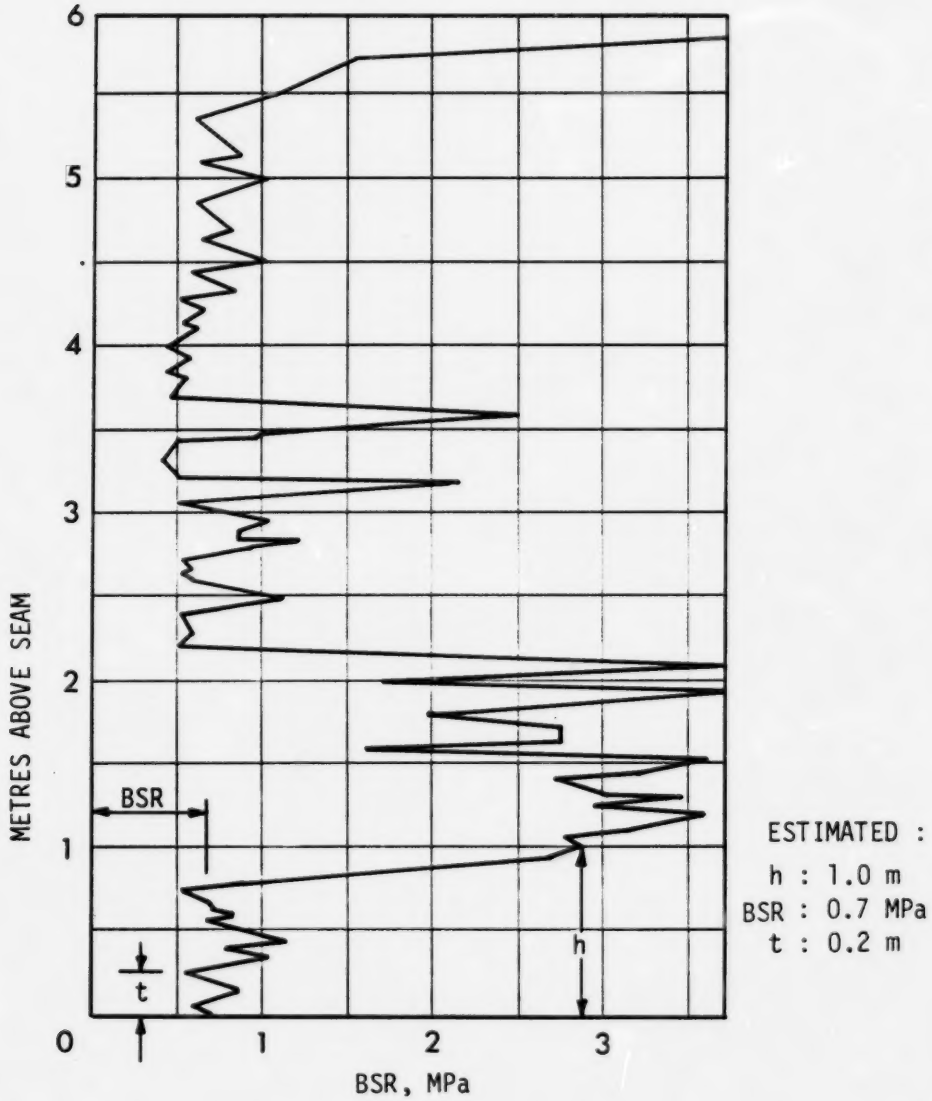


FIG. 8

LOG OF BED SEPARATION RESISTANCE
(SEAM 410-2/412, NOWA RUDA MINE, LOWER SILESIA)

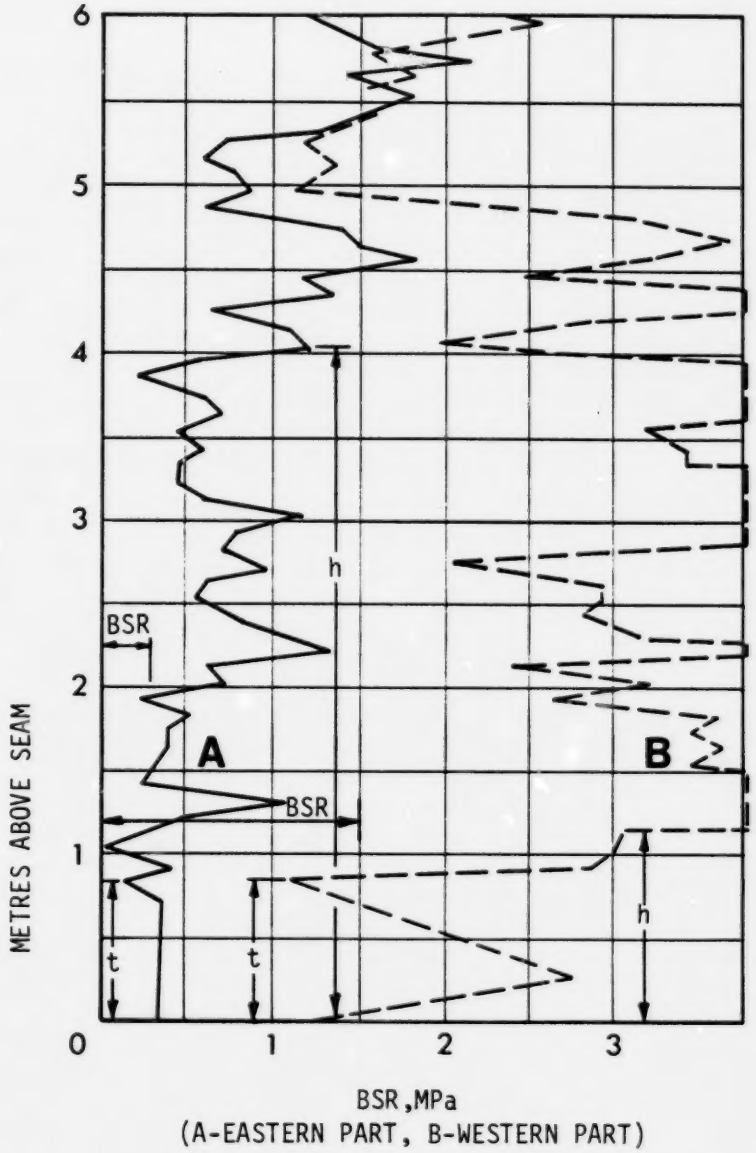


FIG. 9

LOG OF BED SEPARATION RESISTANCE
(HUB SEAM, PRINCE MINE, NOVA SCOTIA)

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.2 Rock Slakeability (Cont'd)

Core samples must therefore be taken of each kind of rock to approximately 2 metres above the seam, and an appropriate volume of mine water should be collected for slakeability testing. Pieces of core each approximately 10 cm long should be placed in the mine water for 24 hours, then taken out for the next 24 hours and immersed again for another 24 hours (a three-day test at room temperature). The state of each sample is assessed after the test and the slakeability factor is found from Table 3. For more precise determinations of SF values, further research would be necessary to develop strength reduction/moisture content relationships for different Canadian rock types. Suggested values are shown in Table 3.

9.2.1 Natural Fractures in Roof Rocks

Natural joints occurring in roof strata play an important role in roof stability. During the driving of roadways, they should be measured and mapped in terms of their frequency, extent, roughness, strike direction and inclination.

A wide variety of geometric situations may affect the self-supporting ability of the immediate roof strata, and no general procedure can be given to predict the strength of an immediate roof layer containing joints. Driving roadways in a direction parallel to the main joints creates a higher roof-fall hazard than in other directions. In most practical cases however, the load bearing capacity of an immediate roof layer containing joints close to vertical may be evaluated at approximately 40 percent of the capacity of the unjointed layer. This is due to the fact that a rock beam with vertical fractures develops a horizontal expansion force which holds the load by a flat arching effect.

TABLE 3 SLAKEABILITY FACTORS OF ROCKS

State of a sample after three-day test	Slakeability Factor
Unchanged	1.0
Rarely broken along bedding planes	0.8
Broken along bedding planes and rarely across	0.6
Densely broken in many directions	0.4
Decayed into fine debris and slime	0.2
Entirely decayed into slime	0.1

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.2.2 CRS Calculation Procedure

Three typical situations may occur in mines in terms of immediate roof stability:

- For rocks insensitive to moisture and without major joints, CRS is calculated using the following formula:

$$CRS = 0.73\ t \sqrt{\frac{BSR}{h}} \qquad (9.2)$$

where BSR, h and t are as defined in Section 9.1.2. As before, BSR is measured in MPa, and CRS, t and h in metres.

- For moisture-sensitive rock, the slakeability factor (SF) should be included, thus:

$$CRS = 0.73\ t \sqrt{\frac{BSR \times SF}{h}} \qquad (9.3)$$

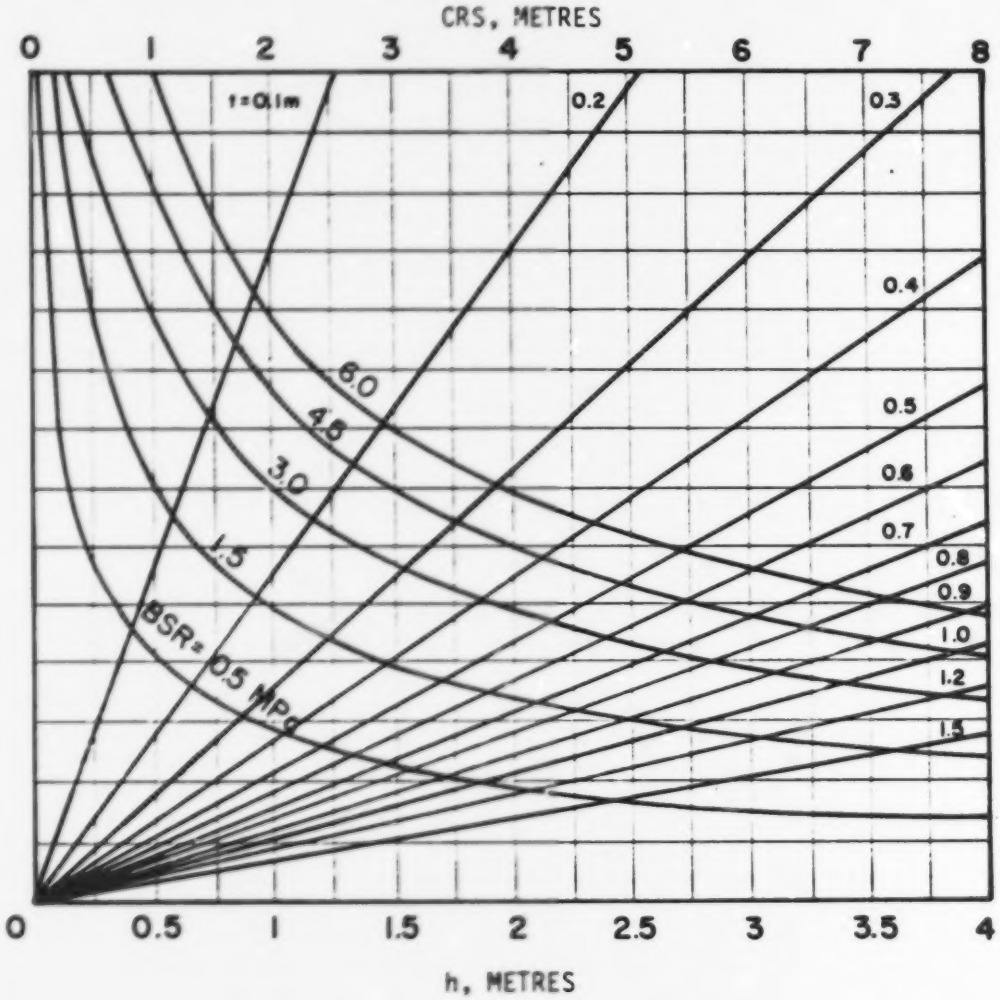
- For roof rocks containing major joints, the result will be approximately:

$$CRS = 0.3\ t \sqrt{\frac{BSR}{h}} \qquad (9.4)$$

In the case of jointed and moisture-sensitive rocks, the effects should be multiplied. In Figure 10 a chart is given for determining CRS according to formula (9.2).

In Table 4 at the end of this Chapter, a classification is given of roof rock according to the CRS value. This can subsequently be used in conjunction with Table 1.

In the case of homogeneous roof rocks (all BSR data within a range of 30 percent of maximum), it may be difficult to assess h and t. Direct BSR values may therefore be used for roof rock classification (see fourth column in Table 4).



KEY

FIG. 10
CRITICAL ROOF SPAN - GRAPHICAL DETERMINATION

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.3 Determination of CRS From Drill Core Data

9.3.1 Evaluation of Essential Parameters

In order to calculate approximate values of BSR from drill core information (and thence CRS), three essential parameters must be known, namely:

- Core recovery ratio
- Core fragmentation ratio, and
- Core splitting resistance.

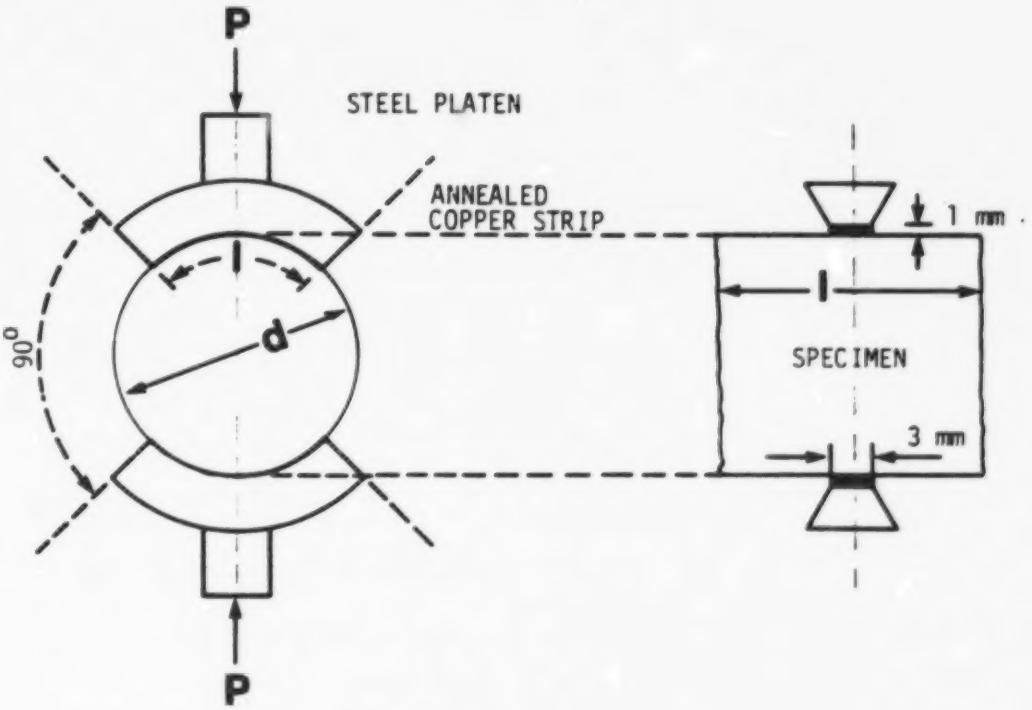
The first two provide rock-mass information and the third gives rock material strength under tensile stresses.

Core recovery ratio (CRR) is defined as the relation of the total core length recovered from the borehole sector analyzed to the respective length of the borehole, and is expressed as a fraction (0.86 for example).

Core fragmentation ratio (CFR) represents the relation of an average length of core fragment (l), measured along the borehole axis, to the diameter of core (d).

Core splitting resistance (CSR) is defined as the critical force required to split a core piece in a Brazilian test with load applied in a direction perpendicular to the core axis. To avoid a point load effect, the force should be applied to the core fragment through appropriately curved platens (see Figure 11). Any type of laboratory testing machine or portable point load strength tester may be used for this test.

All three parameters discussed above should be tested on fresh and unbroken core material, possibly before regular geological treatment. Approximately 10 metres from above and 5 metres from below the coal seam should be taken for inspection, with tests performed on pieces of core one metre in length. At least ten CSR measurements should be taken within a unit, provided the core material is not too fractured, as specimens must have a length of at least 1.0 d along the core axis.



$$l = \frac{\pi d}{4}$$

FIG. 11
SHAPE OF PLATEN FOR CORE SPLITTING RESISTANCE (CSR) TEST

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.3.2 Calculation of BSR

In order to evaluate BSR, core index (CI) is calculated first, as follows:

$$CI = CFR \sqrt{CRR} \qquad (9.5)$$

and then rock-mass factor (RMF) is found:

$$RMF = 0.5\ (1 + \log CI) \qquad (9.6)$$

RMF is defined as the proportion of rock-mass strength to the strength of the intact rock (or rock specimen), and includes the effect of geological defects such as joints, cleats and partings.

Tensile strength (TS) of the intact rock (tensile force along core axis) is found next:

$$TS = 12.7\ \frac{CSR}{d^2} \qquad (9.7)$$

(TS is in MPa, CSR in kN, d in cm)

and finally BSR is calculated:

$$BSR = RMF \times TS \qquad (9.8)$$

An RMF value not higher than 1.0 should be used in this formula, even if the value obtained using formula (9.6) is slightly higher.

9.0 CLASSIFICATION OF ROOF STRATA (Cont'd)

9.3.3 Evaluation of CRS

As with the underground access method, BSR, h and t are essential parameters in evaluating CRS. The same type of BSR logs should therefore be drawn, as shown in Figures A1 to A7 (see Appendix A), and representative values of the three parameters should be found. The routine calculation procedure also includes SF, if required. It should be kept in mind, however, that CRS results obtained through drill-core analysis are rough estimates only.

The classification of roof rocks according to CRS is shown in Table 4.

TABLE 4 CLASSIFICATION OF ROOF ROCKS

Roof Class	CRS, metres (non homogeneous rocks)	Roof behaviour	BSR, MPa (homogeneous rocks)
1	0 - 2	Falls immediately after exposure (including the weakest coal roofs); requires continuous tight lagging with full dead-load bearing support or ripping: heavy flushing into working space from gob and coal dilution	0 - 0.5
2	2 - 4	Falls (shales, mudstones and sandstones) or is partially self-supporting (coal); requires closely spaced support with evenly distributed load-bearing capacity over whole surface exposed; moderate flushing and coal dilution	0.5 - 1.5
3	4 - 6	Partially (shales, mudstones and sandstones) or entirely (coal) self-supporting; caves easily; requires evenly distributed load-bearing capacity of supports	1.5 - 3.0
4	6 - 8	Entirely self-supporting; good stability in narrow openings; caves spontaneously without hanging in the gob	3.0 - 4.5
5	8 - 10	Good roof stability in wide openings and very good stability in narrow openings; difficult caving, short overhangs in gob	4.5 - 6.0
6	more than 10	Very good roof stability in wide openings; very difficult caving, long overhangs in gob, periodical dynamic breaks	more than 6.0

10.0 (..IFICATION OF FLOOR STRATA

10.0 CLASSIFICATION OF FLOOR STRATA

Load bearing capacity is proposed as the basic parameter in establishing the classifications of floor strata according to their stability. It can be determined as described in Section 10.1 when access to floor rocks is available from mine workings. Other tests to be carried out on floor rocks are described in Sections 10.2 and 10.3. When underground access is not available, floor rock classifications are determined from drill cores as described in Section 10.4.

10.1 Load Bearing Capacity

Load bearing capacity (LBC) of the immediate floor rocks is defined as the plate load at rock failure per unit area of the floor surface being loaded.

10.1.1 Direct Plate Load Testing of Immediate Floor Rocks

To perform a direct plate load test, hydraulic jacks of any type may be used but, for simplicity, a single hydraulic prop is often applied as the basic equipment. This should be capable of developing an active thrust force of at least 200 kN and should be furnished with a set of flat circular plates that can be attached to the foot of the prop. A hydraulic pressure gauge should be connected to the system to indicate the actual value of load applied by the prop, and the calibration curve should be known to find the relationship between the actual loads (kN) and the pressure gauge readings. A set of prop extension pipes of various lengths should be provided to enable testing at different roof-to-floor intervals. The diameters recommended for a set of three circular plates are 10.1 cm, 15.8 cm and 28.9 cm. A maximum force of 200 kN applied will produce LBC values of 25, 10 and 3 MPa respectively. The testing procedure starts with the smallest plate, which is pushed into freshly exposed, smooth, clean floor rock until failure occurs, and the critical load is noted. The medium sized plate is then used in a location at least 0.5 m away from the first test site. If the test is successful (floor failure is achieved), the large plate is used at another fresh place on the floor. Critical loads obtained should be divided by the respective plate areas (80, 200, or 666 cm^2) to calculate LBC.

10.0 CLASSIFICATION OF FLOOR STRATA (Cont'd)

10.1.1 Direct Plate Load Testing of Immediate Floor Rocks (Cont'd)

The calculated LBC value leads directly to floor classification, which will be discussed later.

If large-scale problems (such as selection of powered supports or tolerance for tracked equipment) are to be solved, it should be kept in mind that LBC is a highly scale-dependent factor. In competent rocks such as siltstones and mudstones, LBC drops rapidly as plate area increases, due to the distribution of structural rock defects. In soft rocks such as weak shales and clay-like mudstones, LBC increases slowly with plate area due to friction and the confinement effect. This relationship is illustrated in Figure 12.

Since large-scale plate load tests are difficult to perform under operating conditions in coal mines, extrapolation techniques may be used to assess large plate area LBC values. To this end, a minimum of three tests are essential with various plate areas, and a local relationship curve is drawn for LBC versus plate area. It would be useful to develop such relationships for the main coal provinces of Canada. A curve is extrapolated to the plate area desired and an appropriate value is found for LBC.

Direct plate load tests require a team of three people, who can produce one triple test per shift. To achieve more is difficult due to the relocation of heavy equipment and preparation procedures for local roof conditions.

10.1.2 Indirect Testing

To avoid difficulties and speed up measurements, an indirect method may be used based on dynamic floor indentation. Different devices and procedures are available, provided a relationship between LBC and impact indentation rate (IIR) is known.

The portable impact floor tester recommended here is illustrated in Figure 13. It weighs approximately 10 kg and consists essentially of a drop weight, plunger and indenter.

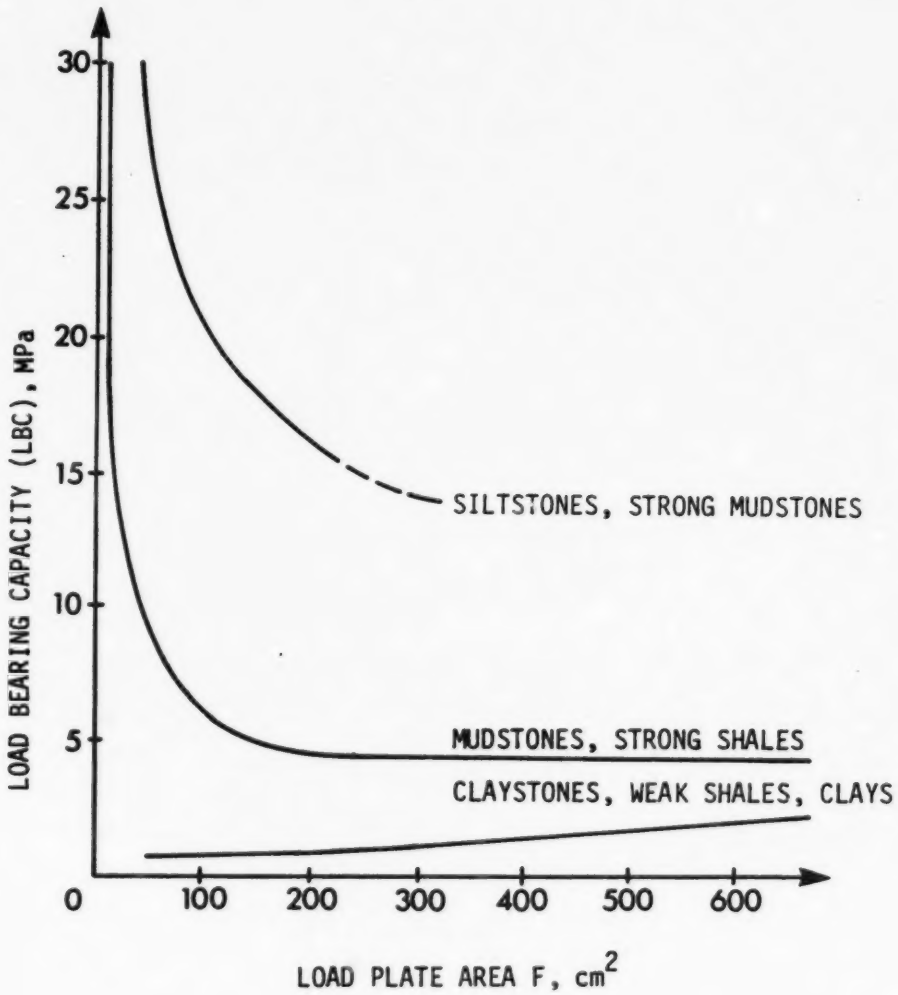


FIG. 12
EFFECT OF SCALE ON LOAD BEARING CAPACITY

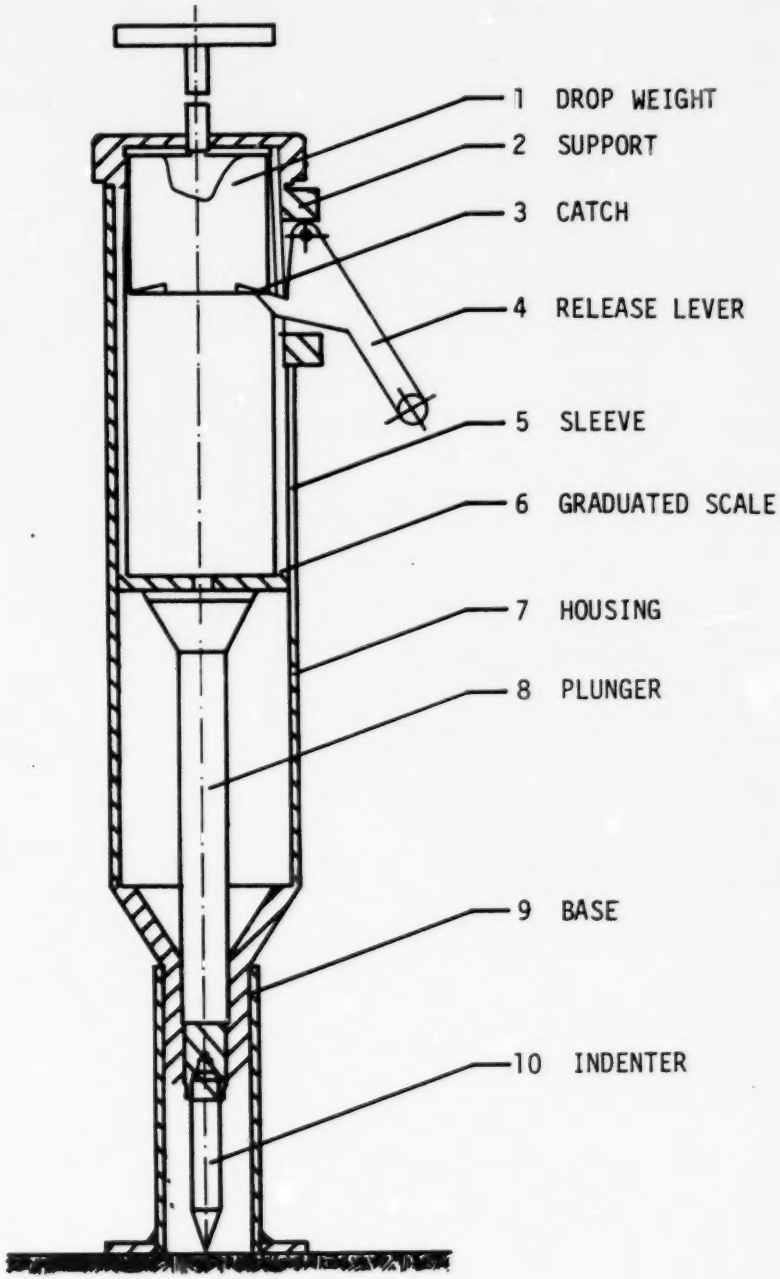


FIG. 13
IMPACT FLOOR TESTER

10.0 CLASSIFICATION OF FLOOR STRATA (Cont'd)

10.1.2 Indirect Testing (Cont'd)

The drop weight is released by a lever and then pulled up with a handle. Impact energy transmitted through the plunger causes the indenter to penetrate the floor, and a penetration depth reading is read from the scale after the 15th and 25th impacts. A single test consists of 25 impacts and 10 tests at various points over a floor area of approximately 1.0 m^2 should be made for calculation of the mean IIR value. IIR is the differential penetration depth, expressed in mm, between the 15th and 25th impacts.

10.1.3 Relationship LBC/IIR

The empirical relationship between LBC and IIR is shown in Figure 14. For a higher accuracy of LBC evaluations, it is recommended that local LBC/IIR relationships be developed for various Canadian coal provinces through simultaneous LBC and IIR tests at the same locations. If IIR is known, the load bearing capacity of a floor may be established.

IIR tests require one qualified person who can take 30 to 50 single measurements during a shift.

10.2 Floor Rock Slakeability

The results of direct or indirect LBC tests performed on freshly exposed rock represent maximum LBC values unaffected by the rock slaking process. It is therefore worth taking floor rock samples from LBC test locations for the slakeability test described in Section 9.2. SF value multiplied by LBC test results will give more reliable operational information concerning floor behaviour over longer periods in the life of a mine.

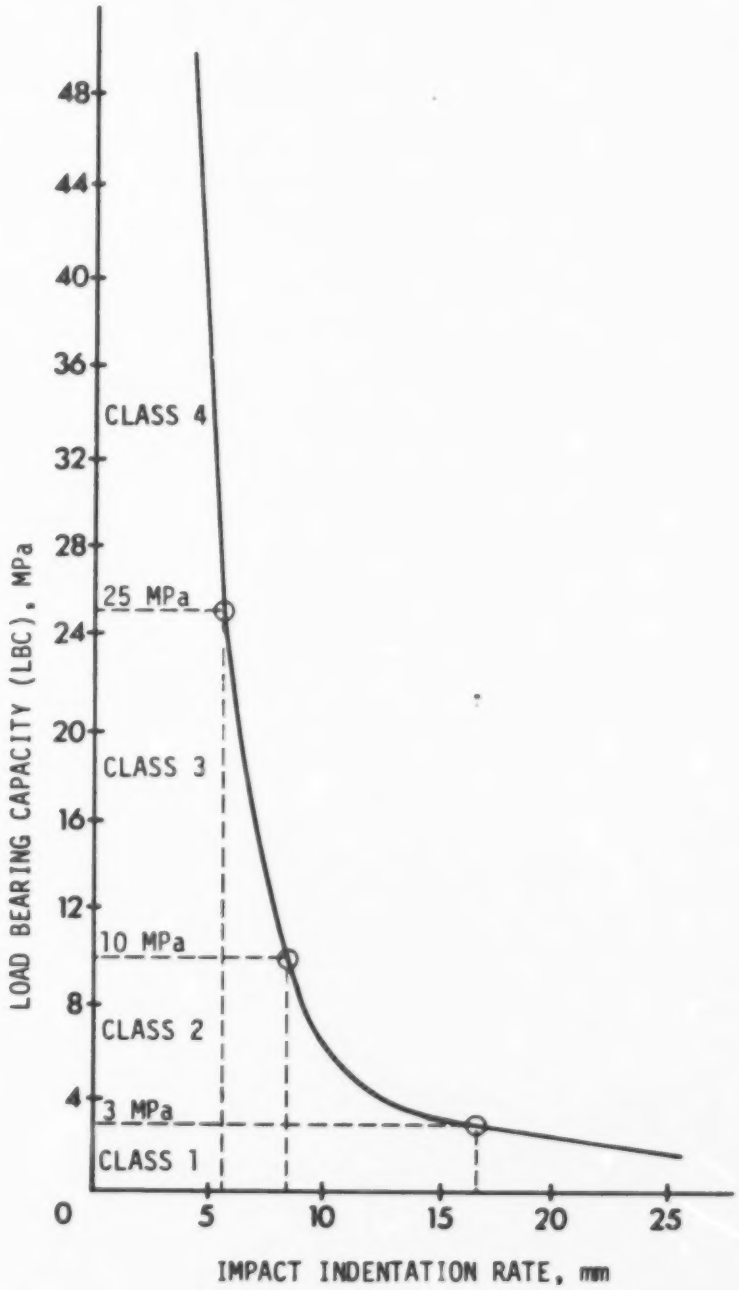


FIG. 14

RELATIONSHIP BETWEEN LOAD BEARING CAPACITY (LBC) AND IMPACT INDENTATION RATE (IIR)

10.0 CLASSIFICATION OF FLOOR STRATA (Cont'd)

10.3 Effective Strength of Main Floor Rocks

LBC test results based on floor surface properties do not provide information concerning floor heaving potential or the critical depth of workings in terms of floor strata distortion.

It is therefore recommended that during roof strata testing with the hydraulic borehole penetrometer, vertical boreholes into floor strata also be drilled (3-5 m long, 86 mm dia.) and HBP tests identical to those in the roof boreholes be performed. HBP equipment is waterproof and can work in boreholes filled with water, but for reliable results the boreholes should be tested soon after drilling. LBC logs may then be drawn as shown in Figures A1 to A7 (lower part of graphs), and LBC values calculated from test results:

$$LBC = 1.2\ p_m \qquad (10.1)$$

(where p_m is maximum oil pressure reading at penetration).

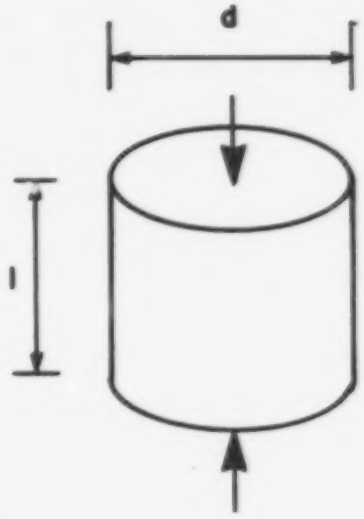
In formula (10.1), LBC is represented by uniaxial compressive strength values. This simplification is justified, because for many coal-measure floor rocks the effect of confinement is equivalent to the scale effect.

10.4 Determination of LBC from Drill Core Data

10.4.1 Evaluation of Essential Parameters

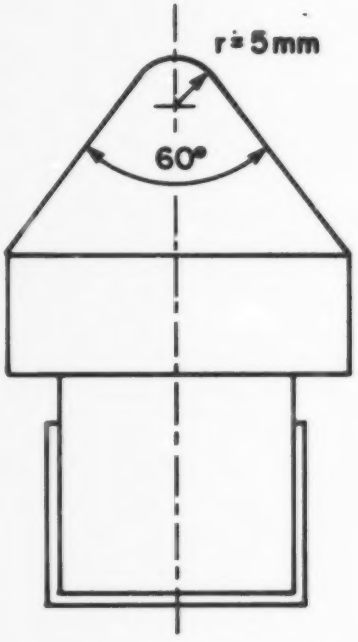
Four parameters must be known to calculate the expected LBC value from core analysis data, namely core recovery ratio (CRR), core fragmentation ratio (CFR), slakeability factor (SF) and point load strength index (PLSI). Three of these have been explained previously (see Sections 9.2 and 9.3). Point load strength index (PLSI) is defined as the load at rock failure (FL) during axial point load testing divided by the area of the vertical fracture of the specimen (Figure 15):

$$PLSI = \frac{10 \times FL}{1 \times d} \qquad (10.2)$$



$\frac{l}{d} = 1.1 \pm 0.05$

A AXIAL TEST



B DIMENSIONS OF PLATEN

FIG. 15
DETERMINATION OF POINT LOAD STRENGTH INDEX (PLSI)

10.0 CLASSIFICATION OF FLOOR STRATA (Cont'd)

10.4.1 Evaluation of Essential Parameters (Cont'd)

where PLSI is in MPa, FL is in kN, l is the length of the piece of core in cm, and d is core diameter in cm. In order to measure FL, any type of point load strength tester or laboratory press may be used, provided appropriate axial platens (see Figure 16) are attached. It is recommended that a universal portable point load strength tester with interchangeable platens be used for the testing of both roof and floor rocks (compare Figure 11 for the testing of roof rocks).

It should be mentioned here that two difficulties may be encountered during PLSI testings of coal-measure rocks. The first is lateral slip, which may occur when the borehole axis is not exactly normal to the bedding planes (or if a vertical borehole crosses inclined strata). In this case, the load should be applied normal to the bedding planes at an angle to the core axis. The value of l is to be understood as the interval between the platens, and d should be adjusted properly to express the area of vertical fracture of the specimen. The second difficulty arises for densely stratified rocks (shales, siltstones) where it is hard to find core specimens with proper l/d ratio and partial lateral failure may occur. The solution in this case is to reduce the size of the specimen (by testing axial half of a core for example), while maintaining the proper l/d ratio (approximately 1.0).

10.4.2 Calculation of LBC

If the core diameter is not 50 mm, PLSI value should be corrected by using the chart shown in Figure 17. LBC is then calculated using the following formula:

$$LBC = 12 \times PLSI \times RMF \times SF \qquad (10.3)$$

where both LBC and PLSI are in MPa, and RMF is calculated according to formula (9.2), using appropriate CRR and CFR values.

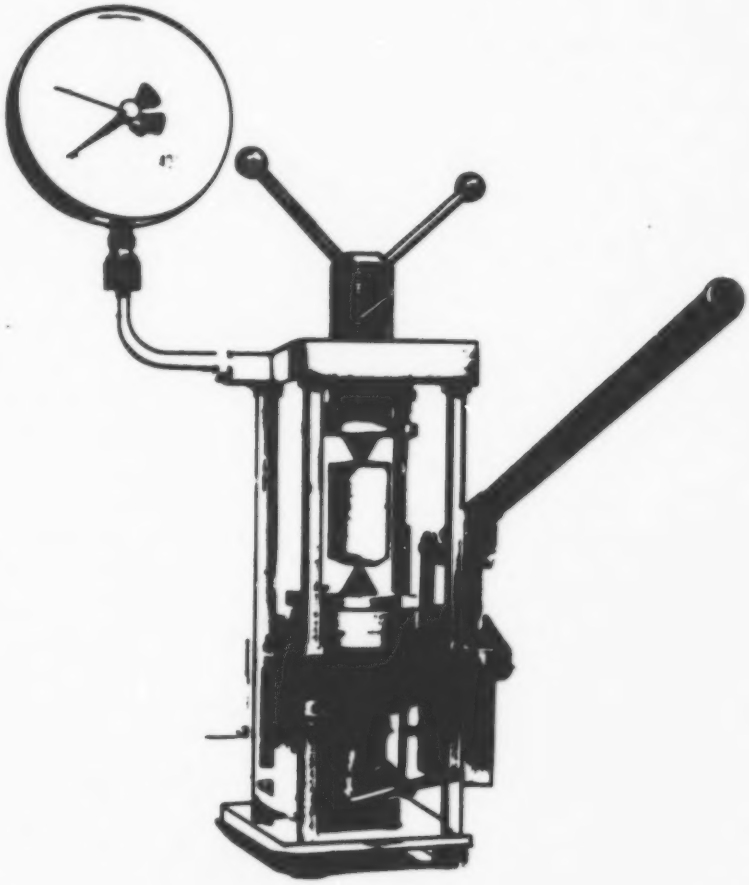


FIG. 16
TESTING OF POINT LOAD STRENGTH, USING AXIAL PLATENS

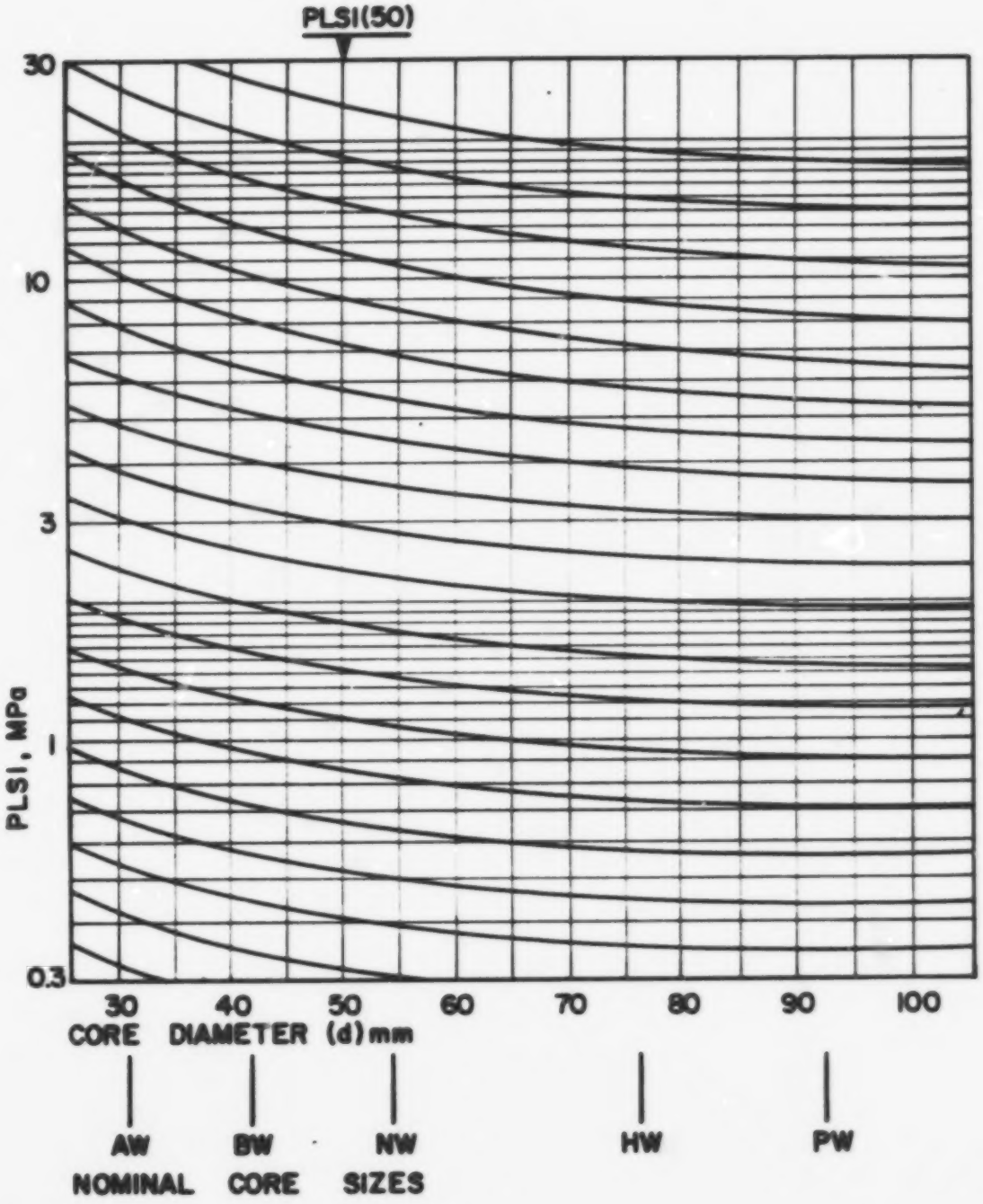


FIG. 17

SIZE CORRECTION CHART
POINT LOAD STRENGTH INDEX

10.0 CLASSIFICATION OF FLOOR STRATA (Cont'd)

10.4.2 Calculation of LBC (Cont'd)

The classification system based on load bearing capacity of immediate floor rocks is shown in Table 5. As with the classification of roof rocks, this table can be used in conjunction with the general classification appearing in Table 1.

TABLE 5 CLASSIFICATION OF IMMEDIATE FLOOR ROCKS ACCORDING TO LBC RATING

Class of floor rock	Load bearing capacity (LBC), MPa	Floor behaviour				
		Moisture	Powered supports	Track tolerance	Individual hydraulic props	Roadway support legs
1	0 - 3	Very weak, highly sensitive; requires careful drainage	Unstable, difficult to advance, not recommended in seams more than 2.0 m thickness	No tyre wheel traffic tolerance, artificial road pavement essential	Floor perforation, no roof supporting ability; footplates essential	Extensive floor perforation, footplates essential
2	3 - 10	Weak, sensitive; requires drainage	Partially unstable, requires lateral constraint, not recommended in seams more than 3.0 m thickness	Occasional tyre wheel traffic possible; under permanent use reinforced road surface or artificial pavement recommended	Limited capacity, footplates recommended	Moderate floor perforation, footplates highly recommended
3	10 - 25	Medium strength, slightly affected	Stable in seams over 3.0 m thickness	Suitable for heavy traffic in dry openings	Good capacity for 200 kN props	Limited floor perforation
4	More than 25	Strong, not affected	Perfectly stable in seams over 4.0 m thickness	Generally suitable for heavy underground traffic	Very good capacity for all types of hydraulic props	No floor perforation, good roof supporting capacity for arches and square sets

11.0 MINING METHODS AND GEOTECHNICAL CONDITIONS

11.0 MINING METHODS AND GEOTECHNICAL CONDITIONS

A brief list of the most common mining methods is given in order to indicate the principal geotechnical parameters affecting the selection of each.

11.1 Room-and-Pillar Method

Conditions under which room-and-pillar mining might be appropriate include the following:

- Relatively shallow depths (less than 750 m) so that coal left in pillars, or lost during pillar recovery, is not excessive.
- Coal pillars are strong enough to support the overlying strata if no subsidence is to be tolerated.
- There is no danger of spontaneous combustion.

Geotechnical requirements for successful use of this method include:

- Roof rock strong enough to stand unsupported over the width of cutting machinery (e.g. continuous miners) until additional support (such as rockbolts, straps, or split sets) can be installed.
- With the additional support, the roof should stand until pillars are withdrawn and caving induced.
- For successful pillar recovery, overlying strata should cave without difficulty in order to avoid build-up and sudden release of stress (bumps).
- Floor rock strong enough to support trackless equipment (continuous miners, shuttle cars).
- If the mine is wet, the floor rock must be resistant to slaking.
- Floor rock strong enough to support pillars.

11.0 MINING METHODS AND GEOTECHNICAL CONDITIONS (Cont'd)

11.2 Longwall Mining

Longwall mining may be selected for some of the following reasons:

- The need to maximize extraction of the resource:

  a) for economy

  b) in case of coal subject to spontaneous combustion

  c) in order to promote even subsidence under critical surface structures, cities, etc., and in submarine areas

  d) in order to avoid leaving pillars that will fail at depth. Longwall has been used from depths of 130 m to 1,400 m. Depths over 350 m are preferred.

- The need to mine thin seams (down to 0.8 m), where other types of equipment cannot be used (maximum thickness that can be mined with existing equipment in one pass is 4.5 m).

Geotechnical requirements for successful longwall mining include the following:

- A weak roof that will cave continuously and evenly behind the line of powered supports.

- A floor strong enough to support the equipment (especially powered supports or hydraulic props)

- Large areas of undisturbed seam, free of faults and folds

- Alignment of the face at right angles to the principal direction of jointing

- Floor strong enough to support roadway arches.

11.0 MINING METHODS AND GEOTECHNICAL CONDITIONS (Cont'd)

11.2 Longwall Mining (Cont'd)

Longwalls may vary in length from 30 m to 200 m depending on seam conditions. The shorter longwalls (30-80 m) may be used in the following circumstances:

- To allow multiple entries.
- To avoid disturbing the surface at the shallower depths.
- To restrict the extent of arching and the height of the caving zone.

11.3 Shortwall Mining

Shortwall mining may be adopted for the following reasons:

- To recover more coal than room-and-pillar mining under appropriate conditions.
- To effect a transition between room-and-pillar and longwall systems. (Use of existing continuous miners and shuttle cars, introduction of powered supports).
- To mine coal seams from 1 m to 4.5 m in height (maximum capability of continuous miner).

The following geotechnical considerations apply:

- Suitable for depths of 30 m - 300 m.
- Roof should be strong enough to stand unsupported over width of mining machinery (for continuous miner, about 3 m between face and supports).
- Roof, with support from rockbolts etc., should be self-supporting across span of entries to allow passage of shuttle cars and other equipment.

11.0 MINING METHODS AND GEOTECHNICAL CONDITIONS (Cont'd)

11.3 Shortwall Mining (Cont'd)

- Roof must cave readily behind support line.

- Floor rocks should be strong enough to support pillars and hydraulic supports, and also to withstand travel of trackless vehicles.

11.4 Hydraulic Methods

Hydraulic mining, as practiced at B.C. Coal's Balmer South Mine for example, is a special case of sub-level caving where water is used for breaking the coal as well as for its subsequent transportation. Hydraulic methods can also be applied to room-and-pillar mining (Ref. 20).

In general, requirements are that the coal be amenable to hydraulicing (the application of monitor jet technology) and that flumes at a slope of 7° to 12° can be used to carry the coal away from the working area. The coal seam itself should have a dip of at least 17°. While it is preferable to take advantage of gravity whenever possible, hydraulic mining has been carried out to depths of 800 m in West Germany.

Geotechnical parameters for hydraulic mining include the following:

- A roof that will stand while the coal is recovered and then cave to avoid build-up of stresses (if a "false roof" of shale exists, it can be mined with the coal if thin enough, or supported by leaving coal on the roof if too thick to mine).

- Rocks in both roof and floor that will not deteriorate under the action of water. If they do deteriorate, then coal must be left against the roof or floor as necessary.

11.0 MINING METHODS AND GEOTECHNICAL CONDITIONS (Cont'd)

11.4 Hydraulic Methods (Cont'd)

Hydraulic mining is not appropriate if the roof caves prematurely (shale) or is delayed (sandstone). The time factor is critical to success. M.L. Jeremic (Ref. 20) has proposed a rock classification system for hydraulic mining purposes, based on cores recovered from exploration drilling: very hard, hard, semi-hard and soft. The classification would also include the lithological planes of weakness and the influence of saturation by water. Due to its high porosity, sandstone may deteriorate in strength by as much as 1.7 to 1 when saturated. Jeremic has also proposed classifications of coal seams based on their thickness and dip.

11.5 Other Methods

Variations of the methods listed above and others have been developed to meet particular conditions. These include methods such as top- or bottom-slicing of thick seams, cut-and-fill mining, large hole augering and many others.

One unusual method that has been successfully developed in Russia is that of cable sawing. In this method coal is cut by a cable fitted with crown cutters that is pulled backwards and forwards mechanically to undercut the coal with a sawing motion. For this method to work effectively, the coal seam should be 0.7 to 2.0 m in thickness, dip at an angle between 35° and 55°, be soft enough to be cut by the "saw" and have a weak parting in the roof so that it will release and fall by gravity as the sawing proceeds up-dip from the lower level to the upper one.

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN

12.1 Prediction of Caveability of Roof Strata

The planning of a coal recovery method requires that the roof caveability be known, because high caveability causes roof-falls in the working space and excessive flushing from the gob, while low caveability requires the method to initiate caving. Some strong and massive rocks may not be suitable for caving at all, thereby creating the potential hazard of periodic dynamic roof breaks over a large area of the mine, and destructive seismic shocks.

A roof rock classification system (see Table 4) offers direct information about potential caveability, provided HBP tests have been carried out. A CRS value or BSR logs allow the assessment of geotechnical details of roof strata structure essential for proper designing of roof control measures. Figure 18 shows how roof strata overhang may be evaluated prior to mining.

12.2 Selection of Mining Method Based on Size of Openings

A coal mining system may be characterized by sizing mine openings in accordance with technological requirements such as dimensions of supports and face machinery. Some of these dimensions are shown in Table 6.

In Figure 19, recommendations are given for the selection of the most appropriate mining method from the viewpoint of roof-strata control, based on statistical case analysis. It must be emphasized, however, that the strength of roof strata is affected by roof subsidence and the vicinity of the gob, so that a strength reduction factor should be included for precise calculations.

12.3 Selection of Supports for Roadways

Identification on the BSR logs of the nearest self-supporting horizon within the roof strata permits calculation of the maximum load expected on roadway supports, and selection of the type and spacing of support required (see example in Figure 3). In particular, it gives an answer to the important economic question of whether roof-bolting might be successfully used

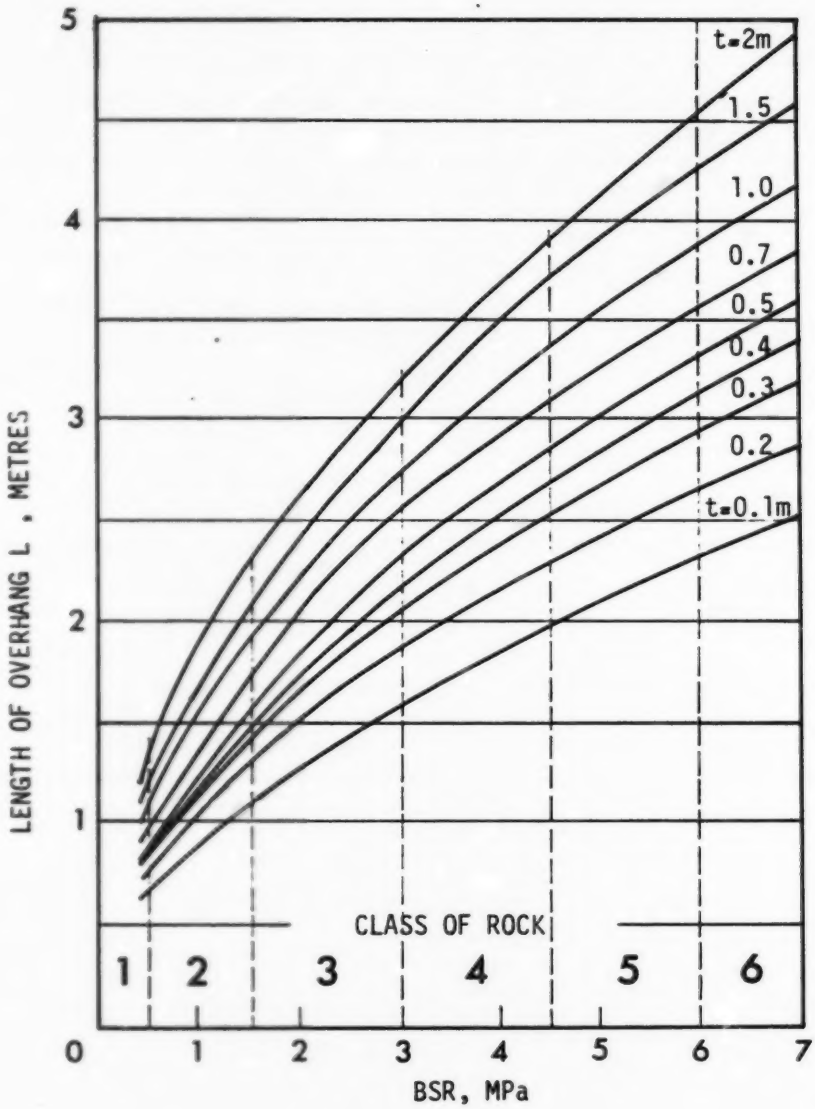


FIG. 18

GRAPHICAL DETERMINATION OF ROOF OVERHANG

TABLE 6 SPECIFIC DIMENSIONS OF OPENINGS IN VARIOUS COAL MINING METHODS

Coal recovery method	Variation of method	Dimensions required, metres
Room-and-pillar mining	Split-and-fender method of pillar recovery	10 x 17
	Modified open-end method of pillar recovery	6 x 12
	Open-end method of pillar recovery	6 x 9
Shortwall mining	Continuous miner and shuttle cars	6 - 7.6 (average 6.8)
Longwall mining	Short longwall shearer-loader and armoured face conveyor	4 - 6 (average 5)
	Chock or frame supports	4.3 - 4.6 (average 4.5)
	Shield supports	1.8 - 3.0 (average 2.5)

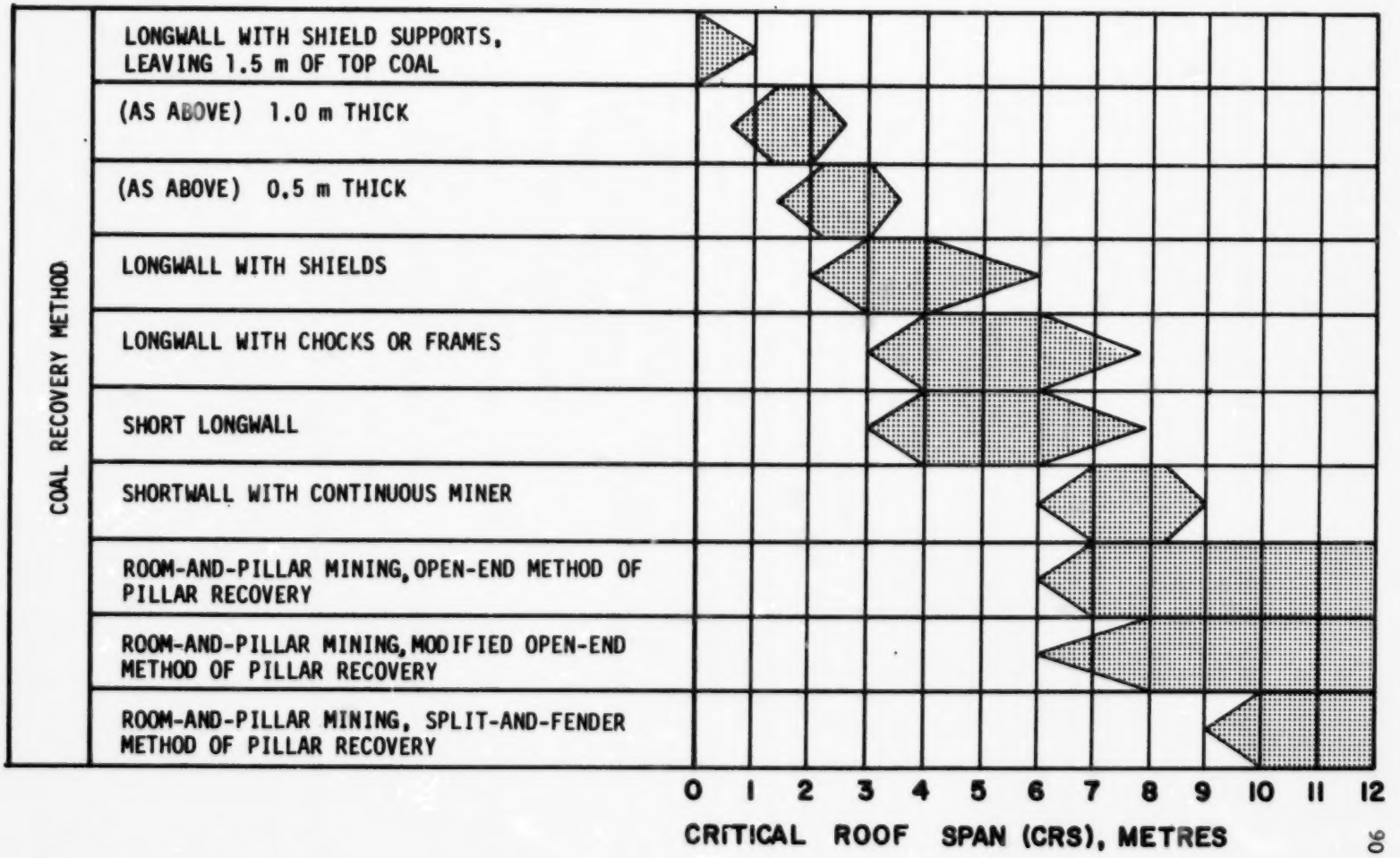

COAL RECOVERY METHOD
LONGWALL WITH SHIELD SUPPORTS, LEAVING 1.5 m OF TOP COAL
(AS ABOVE) 1.0 m THICK
(AS ABOVE) 0.5 m THICK
LONGWALL WITH SHIELDS
LONGWALL WITH CHOCKS OR FRAMES
SHORT LONGWALL
SHORTWALL WITH CONTINUOUS MINER
ROOM-AND-PILLAR MINING, OPEN-END METHOD OF PILLAR RECOVERY
ROOM-AND-PILLAR MINING, MODIFIED OPEN-END METHOD OF PILLAR RECOVERY
ROOM-AND-PILLAR MINING, SPLIT-AND-FENDER METHOD OF PILLAR RECOVERY
0 1 2 3 4 5 6 7 8 9 10 11 12
CRITICAL ROOF SPAN (CRS), METRES
90

FIG. 19

SUGGESTED MINING METHODS FOR VARIOUS CONDITIONS OF ROOF STRATA

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN (Cont'd)

12.3 Selection of Supports for Roadways (Cont'd)

alone as roadway support. Two different calculation procedures for support load requirements are used, depending on ground stress conditions and average working depth. General recommendations for roadway supports based on CRS values are given in Figure 20. These apply to shallow depth conditions where a simple beam-based calculation procedure can be used.

12.4 Roof-bolting Practice: Length and Spacing of Bolts

It is well known that two basic modes of bolting may be used depending on roof-strata properties. The first is the securing of weak layers to a strong bolting horizon and the second is the joining of thin layers together into one thicker, friction-held beam. Detailed roof-strata structure identification with BSR logs is therefore most useful in selecting the proper length and spacing of bolts. It allows the choice of the proper bolting mode and the application of specific geotechnical requirements for various types of bolts, e.g. expansion bolts (steel or rubber heads), resin-anchored bolts, split sets. Figure 2 gives an example of determining the roof-bolting horizon within roof strata.

12.5 Selection of Face Support

Load-bearing capacity requirements on face supports are defined by three factors:

- Overall load-bearing capacity of a support unit
- Setting load/working load ratio
- Position of resultant force of support (i.e. distance from the face).

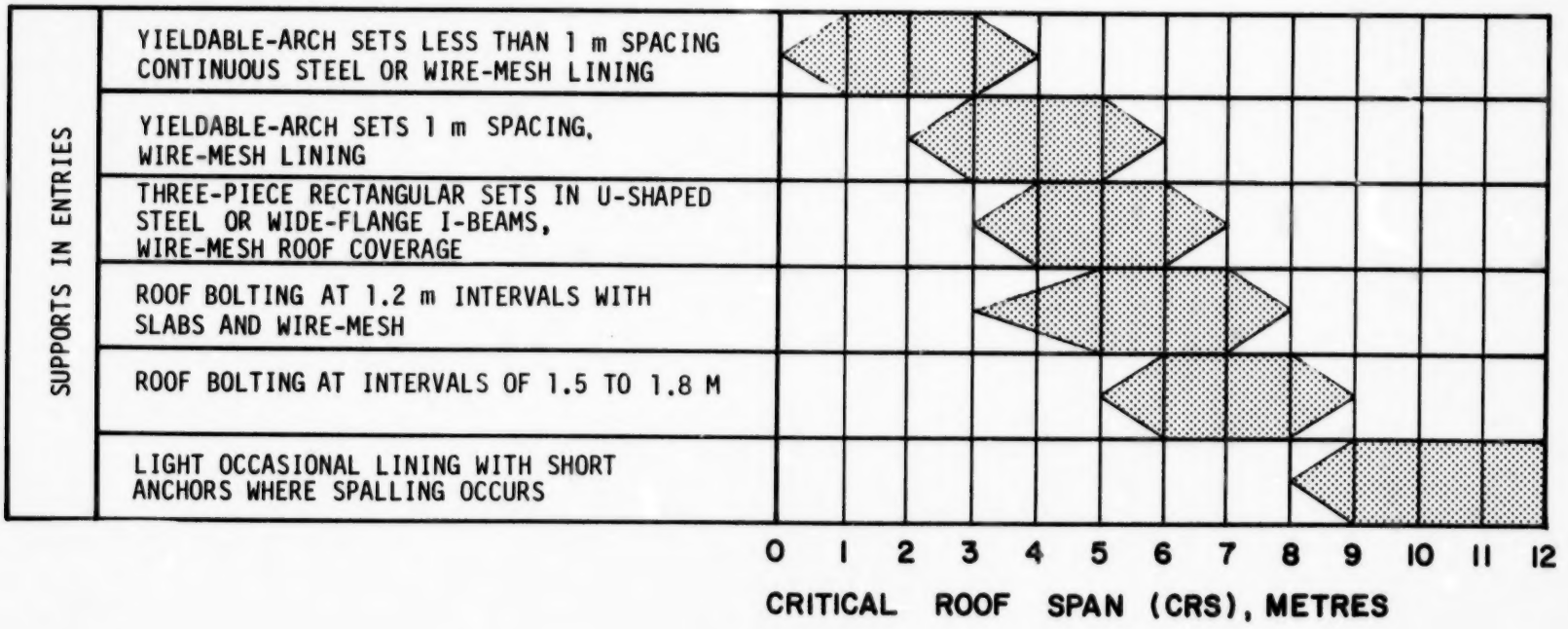

SUPPORTS IN ENTRIES
YIELDABLE-ARCH SETS LESS THAN 1 m SPACING CONTINUOUS STEEL OR WIRE-MESH LINING
YIELDABLE-ARCH SETS 1 m SPACING, WIRE-MESH LINING
THREE-PIECE RECTANGULAR SETS IN U-SHAPED STEEL OR WIDE-FLANGE I-BEAMS, WIRE-MESH ROOF COVERAGE
ROOF BOLTING AT 1.2 m INTERVALS WITH SLABS AND WIRE-MESH
ROOF BOLTING AT INTERVALS OF 1.5 TO 1.8 M
LIGHT OCCASIONAL LINING WITH SHORT ANCHORS WHERE SPALLING OCCURS
0 1 2 3 4 5 6 7 8 9 10 11 12
CRITICAL ROOF SPAN (CRS), METRES

FIG. 20

SUGGESTED ROADWAY SUPPORT METHODS AT SHALLOW DEPTHS

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN (Cont'd)

12.5 Selection of Face Support (Cont'd)

All of these factors may be quantitatively established on the basis of BSR logs of roof strata, and the optimum support system for particular roof conditions may be specified. Two main calculation procedures are used, both dealing with the geometry of the roof strata block loading the support. When roof rocks are homogeneous, A.H. Wilson's method (Ref. 21) is applicable. A. Bilinski's method (Ref. 11) is used for non-homogeneous roof strata.

12.6 Multi-Seam Mining

The class of the roof rocks of the coal seam being extracted is a decisive factor in the behaviour of the upper seam. In particular, the vertical range of critical deformation, defined as the multiplication factor for the thickness of the seam being extracted, differs for various roof conditions. It has an immediate impact on future recovery of resources from seams above and roof strata classification can therefore offer a guideline for designing the most appropriate sequence of multi-seam coal extraction.

The subsidence process affects the roof and floor strata of the upper seam, degrading their geotechnical parameters. In some cases, extraction of a lower seam may be beneficial to the roof strata of the upper seams, increasing their caveability for further longwall extraction.

12.7 Properties of Immediate Roof

It has been indicated in Chapter 9.0 of this study that HBP technique makes it possible to detect properties of the roof partings, even if they are very thin. This is of special importance to some coal disintegration methods, such as ploughing, cable-saw mining and hydraulic mining, because these

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN (Cont'd)

12.7 Properties of Immediate Roof (Cont'd)

techniques provide for undercutting the lower part of the seam, with the upper part expected to fall spontaneously. This can only happen when a weak contact exists between the coal and the immediate roof, or weak and continuous partings occur within the immediate roof. It is also important for prediction of the level of dilution due to roof falls, and the percentage of coal seam recovery, which depends on spontaneous spalling of coal from the roof. Both problems may be resolved through careful examination by HBP of the immediate roof and the top layer of coal.

12.8 Dimensioning of Top and/or Bottom Coal

In the case of very poor roof or floor stability, an opening may be protected by leaving a coal band of appropriate thickness against the immediate roof or floor. This is of special importance in the Plains and Foothills, but may be necessary in other coal provinces as well. Sufficient coal strength and properly calculated coal band thickness are required for this to succeed, however. Testing the strength and frequency of joints in the immediate roof/floor strata and adjacent coal layers is therefore essential, after which the rock classification system can be used together with the appropriate engineering criteria. Figure 21 gives a chart for dimensioning the thickness of bottom coal overlying loose or very weak floor rocks (Floor Class 1), and Figure 22 shows the same type of chart for loose or very weak roof strata (Roof Class 1 or 2).

12.9 Selection of Foot Plates

If weak floor rocks do not withstand the unit loads exerted by the legs of entry supports or hydraulic props, appropriate foot plates should be designed and used. This duty is often neglected in mines and floor yield is taken adventage of to protect rigid supports in places where yielding supports should be used due to coal mine strata control requirements. It can only result in perforation, leading to progressive deterioration of the floor and uncontrolled subsidence of the roof.

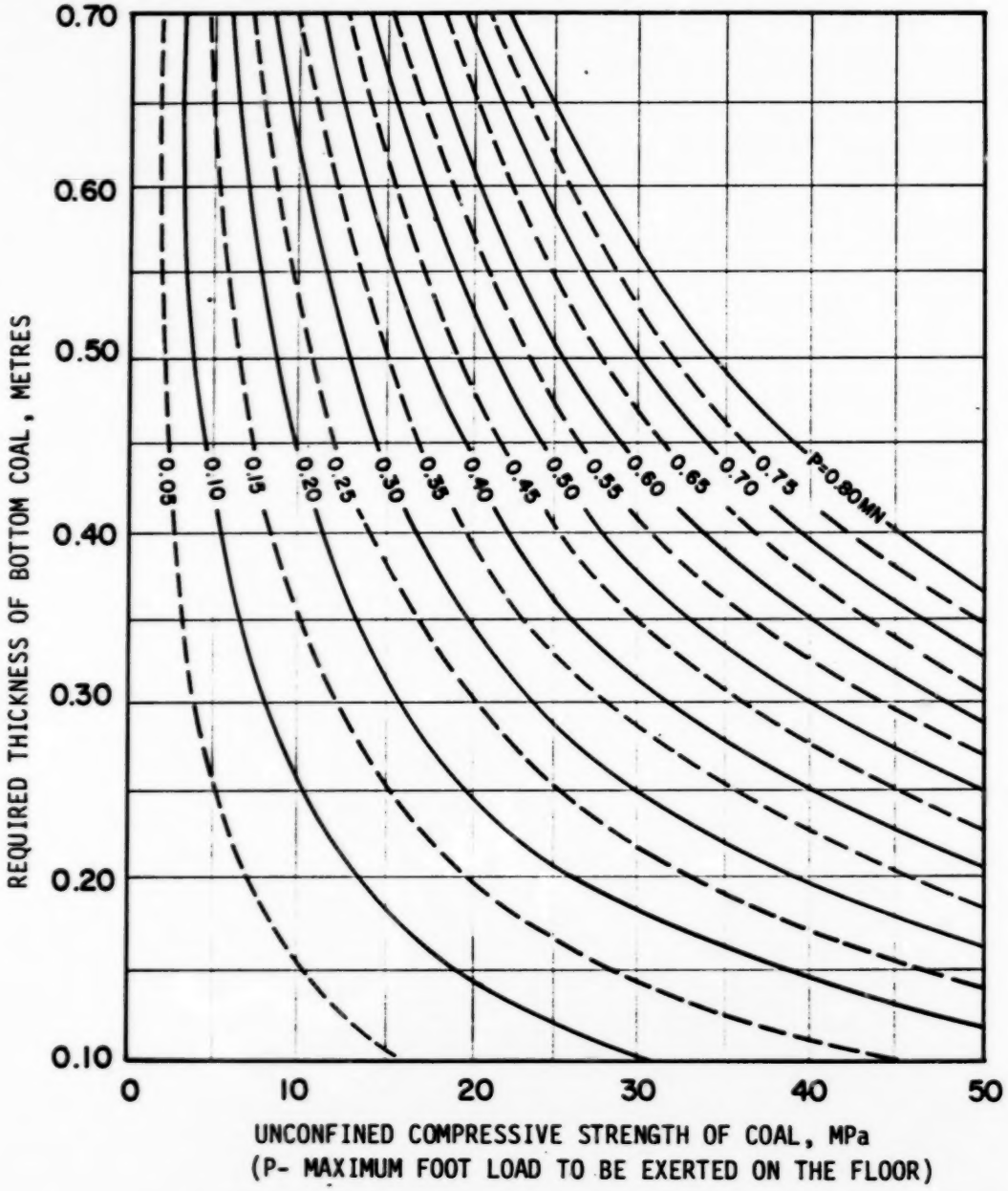


FIG. 21

DETERMINATION OF THICKNESS OF BOTTOM COAL

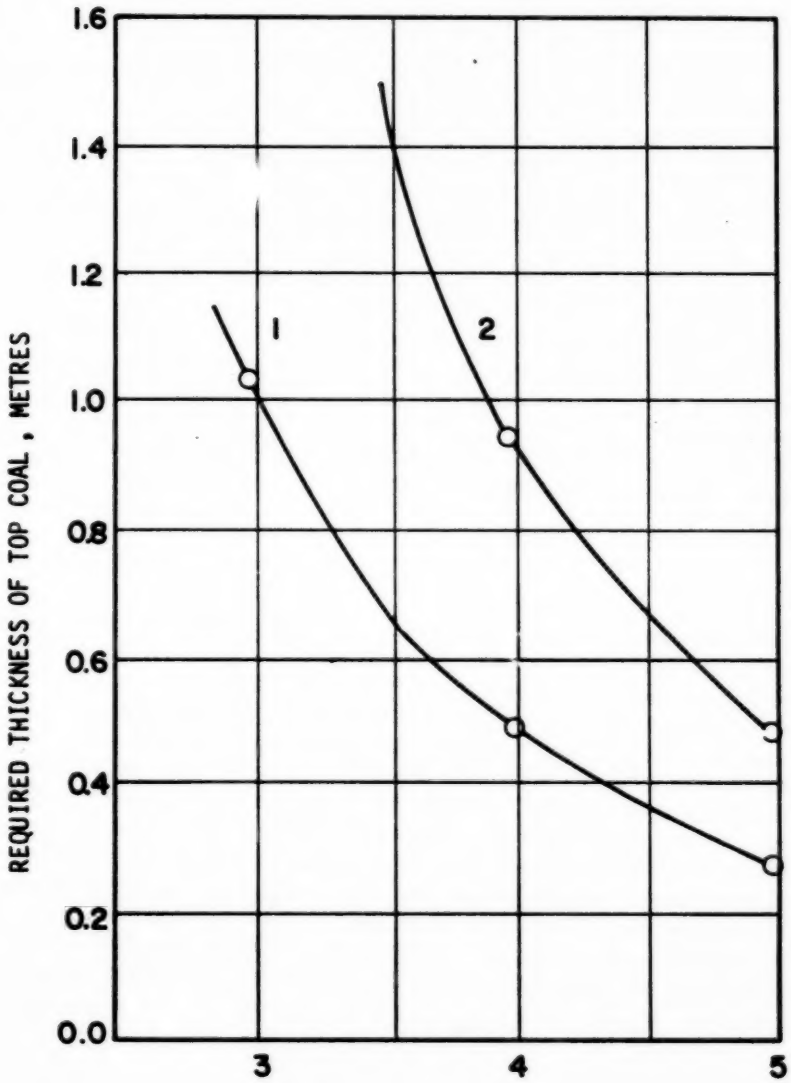


FIG. 22

DETERMINATION OF THICKNESS OF TOP COAL

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN (Cont'd)

12.9 Selection of Foot Plates (Cont'd)

When the floor class is known, a proper size of foot plate may be calculated using critical load approach together with an appropriate safety factor. For their successful use, foot plates must be securely attached to the props.

12.10 Dynamic Loads on Floor Rocks

Track tolerance of floor rocks is a factor of major importance for mines using room-and-pillar and/or shortwall methods. The rock classification system may be used to evaluate prospective track properties of the floor and to design appropriate reinforcement measures if necessary. It is important that the slakeability factor (SF) be used to determine floor properties over the long term.

12.11 Design of Drainage Systems

During mine planning, it is important to predict the behaviour of floor rocks and, if necessary, design a proper water drainage system to prevent floor deterioration. The rock classification system may be used for this purpose by establishing LBC and SF values through the testing of drill core samples or, whenever possible, by the direct testing of LBC and SF in initial development workings. If floor rocks prove to be moisture-sensitive, a system of openings, properly inclined to allow water flow and with sealed side-ditches or pipes and appropriate pumping equipment, should be designed. In extreme conditions, more sophisticated measures such as local water drainage systems (drilled wells with pumps), grouting of floor rocks and sealing screens or paving may be the only way to prevent extensive deterioration of the floor.

12.0 APPLICATION OF ROCK CLASSIFICATION SYSTEM TO MINE DESIGN (Cont'd)

12.12 Critical Depth of Workings

With increased depth of coal mining, working conditions deteriorate due to higher overburden loads causing excessive stresses within main floor rocks and coal pillars. Depending on the class of rocks encountered, the critical depth of workings may vary from less than 200 to more than 1,000 metres. At this depth, dynamic rock pressure phenomena are experienced and massive floor heaving and coal bursting, particularly from pillars, should be expected. Working below the critical depth requires specific measures to maintain mine openings, and closely spaced circular steel arches may be the only solution to prevent roadway closure if the floor rocks do not withstand high stresses. A rock classification system, and specifically strength data on main floor rocks, will allow the prediction of geotechnical conditions with respect to critical depth, thereby avoiding unexpected operational costs.

13.0 CONCLUSIONS AND RECOMMENDATIONS

13.0 CONCLUSIONS AND RECOMMENDATIONS

13.1 Conclusions

Rock classification systems have become an important tool in the design of underground openings and the support required to maintain them, whether permanently for industrial purposes or temporarily for mining purposes. The wealth of different systems that has been developed in the last twenty years attests to their use and importance.

The fact that there are so many systems shows the need for a system to be specific to the conditions for which it is to be used. Canadian underground coal mining conditions are seen to vary from coalfield to coalfield, from mine to mine, and from section to section within a mine.

This initial step in the development of a general classification system for Canadian coal mines is therefore an elaboration of the principles involved, based on previous world-wide experience and a preliminary evaluation of conditions in Canada. From this general basis, more detailed and specific classification systems can be evolved.

13.2 Recommendations

To assist in mine planning and in order to derive maximum benefit from this roof and floor rock classification system, it is recommended that further work be carried out in order to develop the classification for mineability of Canadian coals that has been proposed in Chapter 8.0.

This work should include determination of:

- Cutting resistance, water jet workability, etc.
- Indices for bursting potential of coal and rocks.
- Potential for outbursts of coal and gas.
- Dimensioning and stability of pillars (to include the effect of time on stability, and the reinforcement of pillar ribs).

13.0 CONCLUSIONS AND RECOMMENDATIONS (Cont'd)

13.2 Recommendations (Cont'd)

- Geotechnical variations in coal seams.

Because of the variation in the types of roof and floor rocks in Canadian coal mines, it is recommended that bed separation resistance logs be developed for typical roof strata in each of the main coal regions of Canada. These would be generated by using the hydraulic borehole penetrometer to test active and dormant mines. This information could be transposed on to maps of roof conditions for the major coal seams and become an important guide to the selection of appropriate mining methods.

A third recommendation is that floor measures of major coal seams in the main coal regions be tested and logged to establish local characteristics, such as load bearing capacity, for use in mine planning. These tests would be carried out using the quick simple methods described in this report, and would allow classifications of floor rocks to be developed based on load bearing capacity, impact indentation rate and plate load area. Maps of floor conditions would then supplement the maps of roof conditions for mine planning purposes.

14.0 ACKNOWLEDGEMENTS

14.0 ACKNOWLEDGEMENTS

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This report has been prepared by SNC Inc.

P.M. Ebsworth, P. Eng.
Project Manager

APPENDIX A

FIELD TESTS

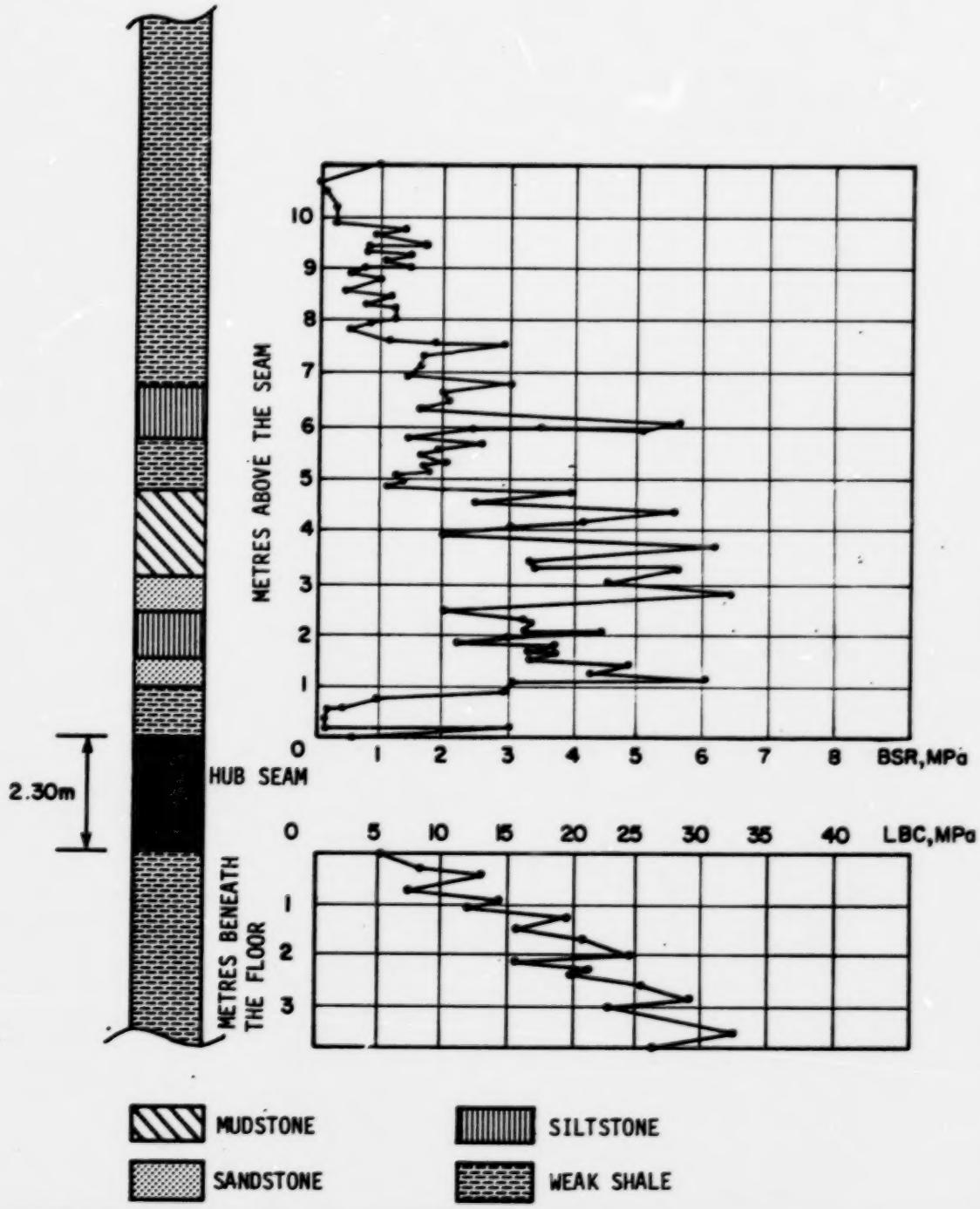

FIG. A1

MARITIMES COALFIELD
HUB SEAM, PRINCE MINE, CAPE BRETON, N.S.
(NW PART OF MINING PANEL)

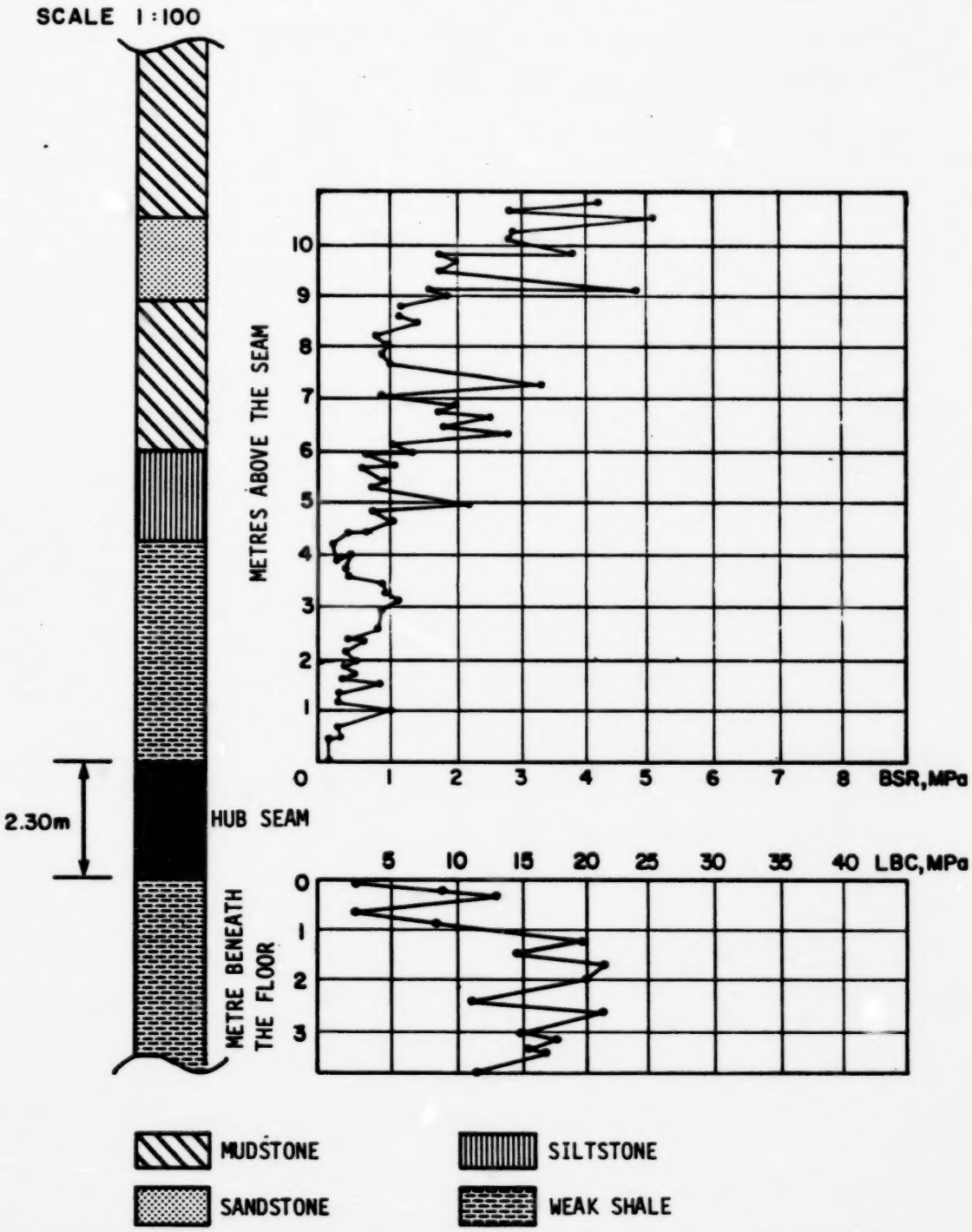

FIG. A2

MARITIMES COALFIELD
HUB SEAM, PRINCE MINE, CAPE BRETON, N.S.
(SE PART OF MINING PANEL)

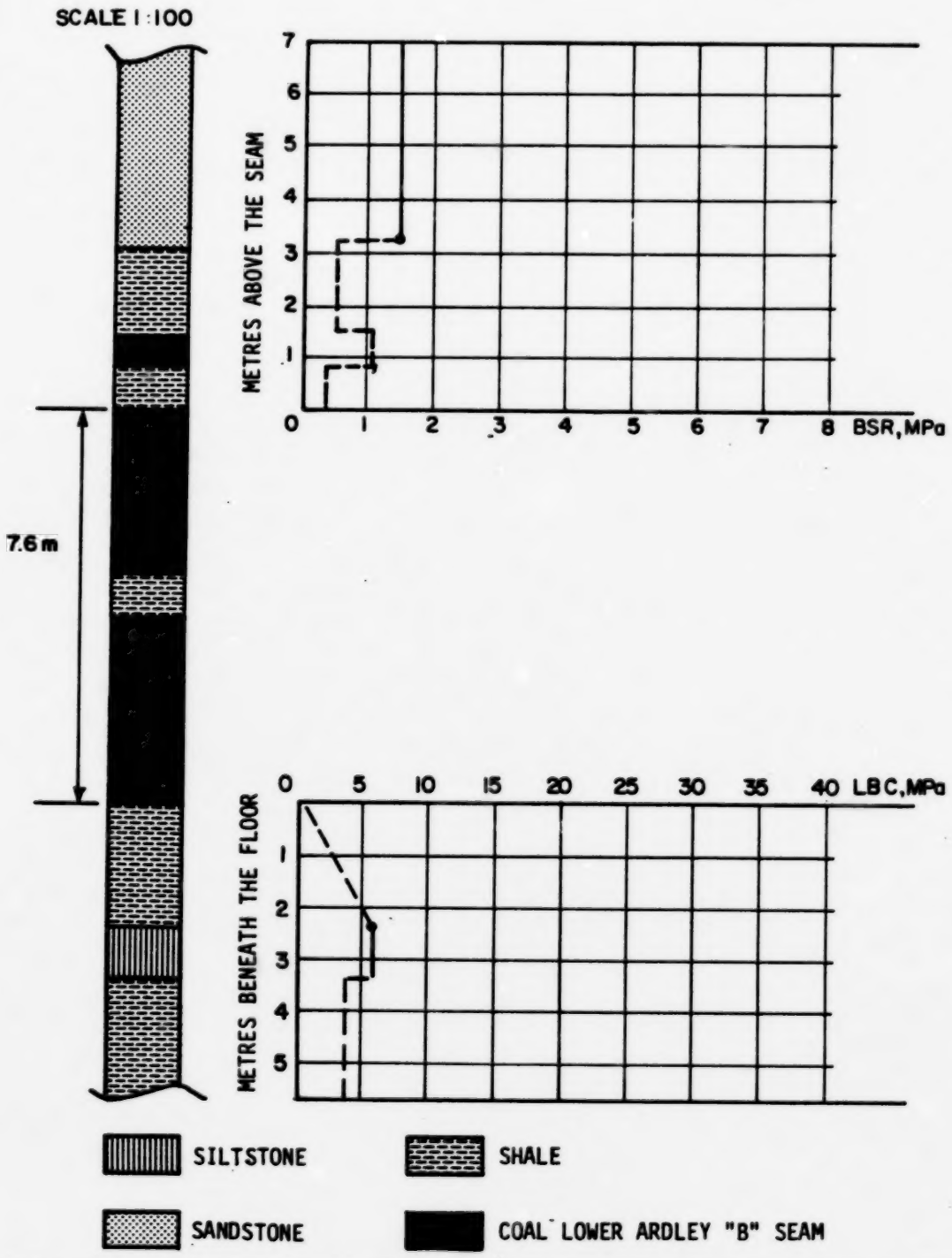
SCALE 1:100
7.6 m
METRES ABOVE THE SEAM
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7 8 BSR, MPa
METRES BENEATH THE FLOOR
0 1 2 3 4 5
0 5 10 15 20 25 30 35 40 LBC, MPa
SILTSTONE
SHALE
SANDSTONE
COAL LOWER ARDLEY "B" SEAM

FIG. A3

PLAINS COALFIELD
LOWER ARDLEY "B" SEAM, RED DEER AREA
(TEST HOLE : ALBERTA RESEARCH TH 20-74 ; APPROXIMATE STRENGTH DATA)

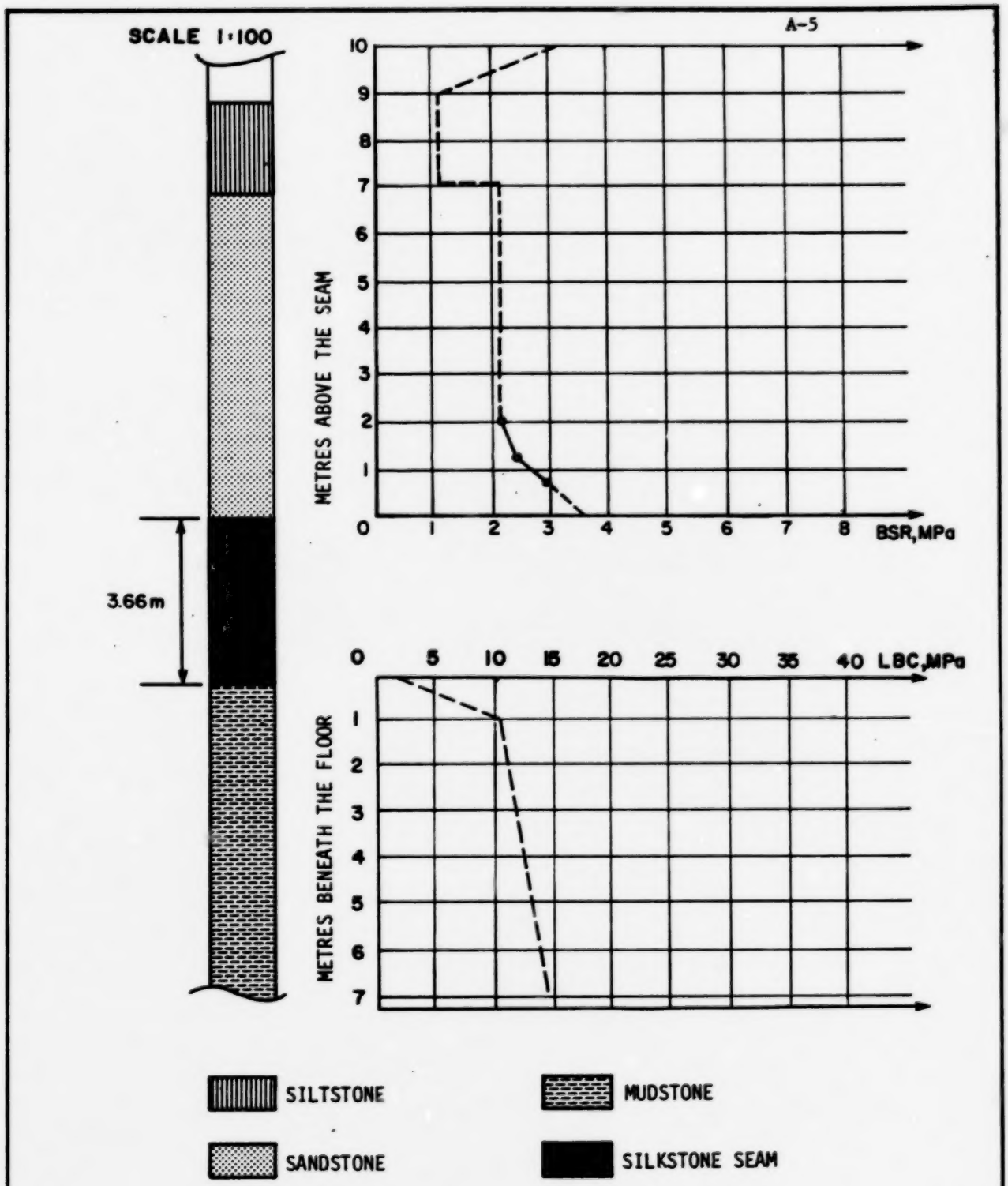

FIG. A4

FOOTHILLS COALFIELD
SILKSTONE SEAM, COAL VALLEY MINE, COAL VALLEY, ALBERTA

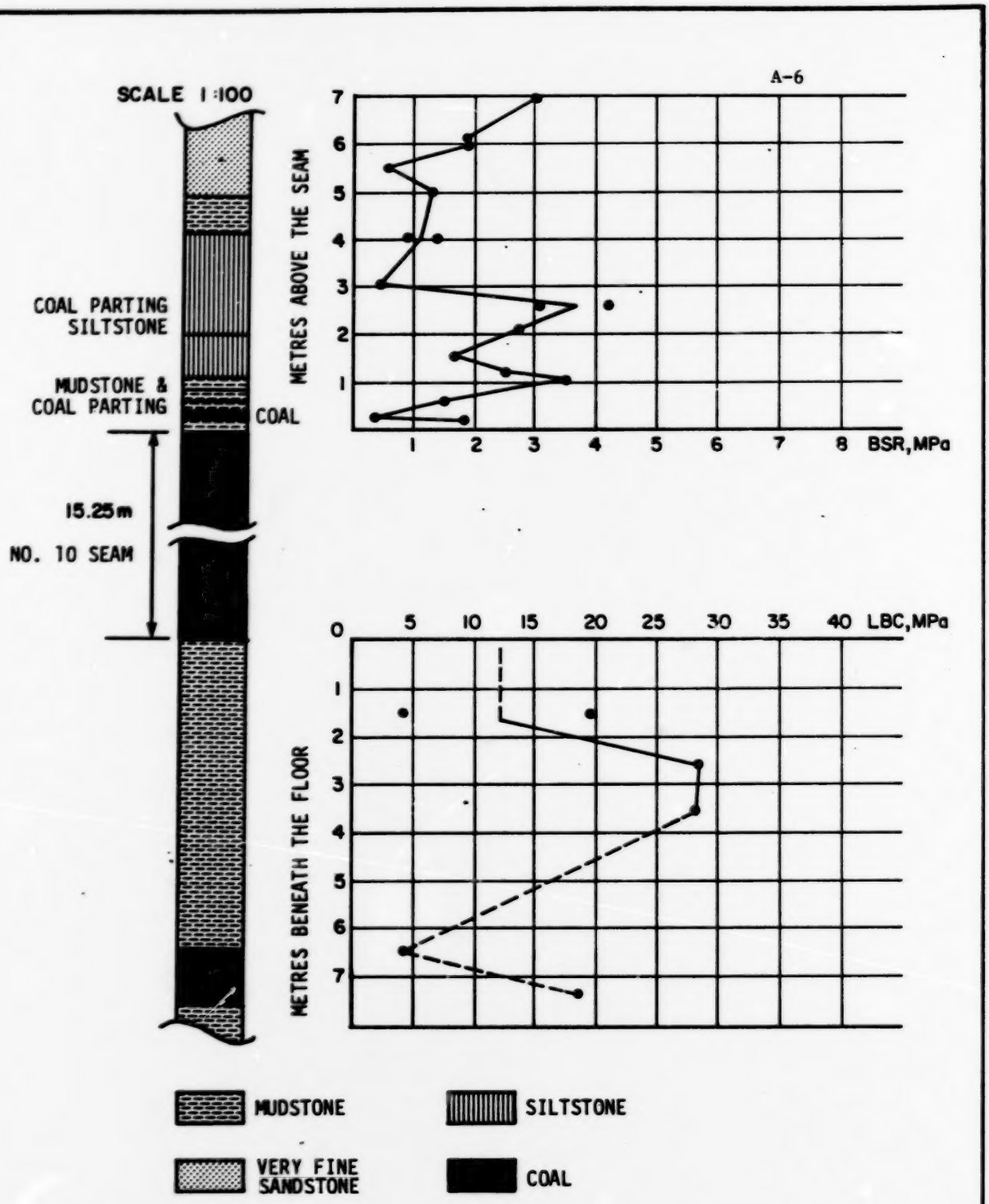

FIG. A5

ROCKY MOUNTAIN COALFIELD
NO. 10 SEAM, BALMER NORTH MINE, SPARWOOD, B.C.

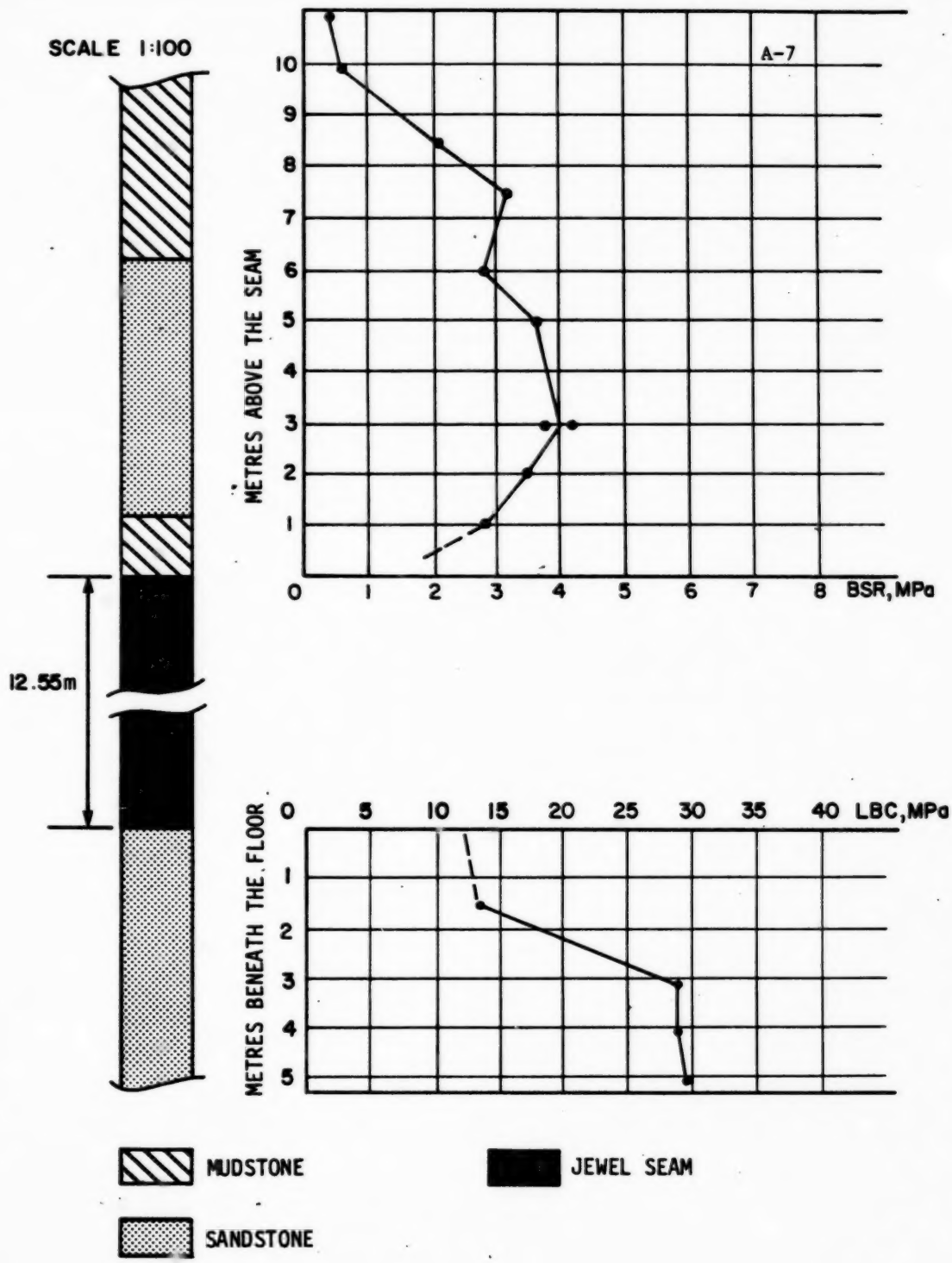

FIG. A6

ROCKY MOUNTAIN COALFIELD
JEWEL SEAM, CARDINAL RIVER COAL MINE, LUSCAR, ALBERTA

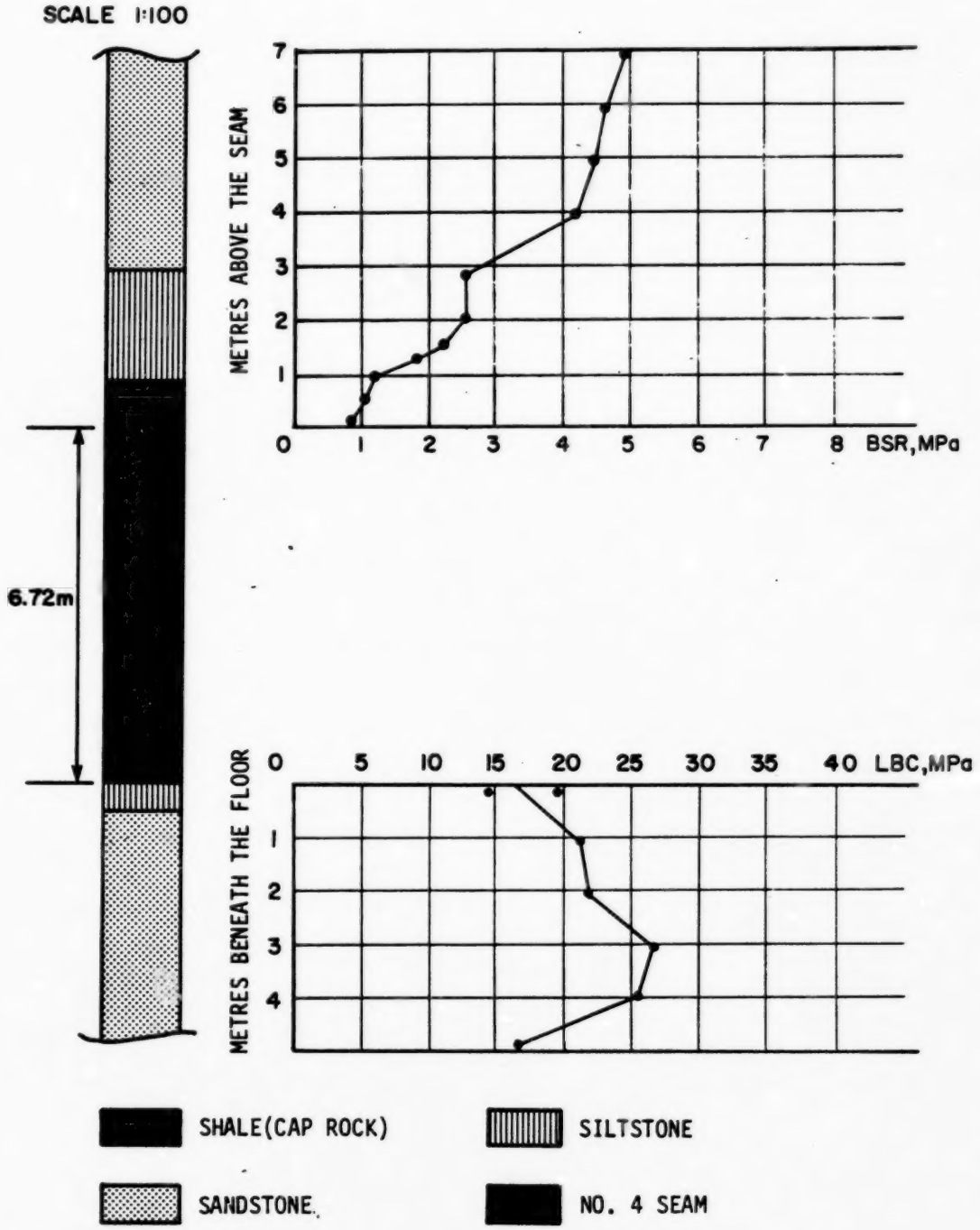
SCALE 1:100
6.72m
METRES ABOVE THE SEAM
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7 8 BSR,MPa
METRES BENEATH THE FLOOR
0 5 10 15 20 25 30 35 40 LBC,MPa
1 2 3 4
SHALE(CAP ROCK)
SILTSTONE
SANDSTONE
NO. 4 SEAM

FIG. A7

ROCKY MOUNTAIN COALFIELD
NO.4 SEAM, SMOKY RIVER COAL MINE, GRAND CACHE ,ALBERTA

APPENDIX B

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APPENDIX C

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APPENDIX D

MAP

"CANADA - COAL"

Energy, Mines & Resources Canada, 1982

POOR

QUALITY

ORIGINAL